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for October, 1938

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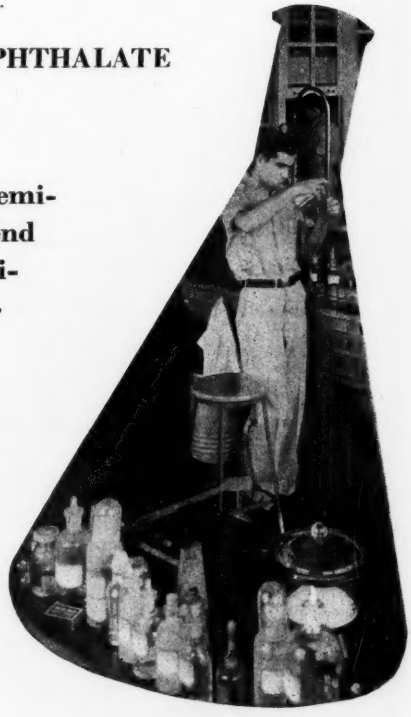

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CHEMICAL WORKS

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N. T. BELAIEW (1878–)

"I was sent to the Michael Artillery School (1896), and there again I had the privilege of listening to the lectures of a set of most brilliant professors... W. N. Ipatieff (now at Chicago), my senior by but ten years; he taught organic chemistry..... Captain Sapojnikoff, a pupil of Mendeléef and an authority in Physical Chemistry."

So wrote the recent Bessemer Gold Medalist, Colonel Nicolas Timothée Belaiew. A student of the famous Russian metallurgist, Professor D. K. Tschernoff of the Michael Artillery Academy; of Professor Wüst of Aachen, and of the late Professor Henry Le Chatelier at Paris, Colonel Belaiew received his training in the early days of applied physical chemistry, and, like the beloved Le Chatelier, devoted his keen observation and fruitful imagination to the newly created science of physical metallurgy.

Born in St. Petersburg on June 26, 1878, of and into a distinguished military family, N. T. Belaiew followed an equally distinguished military and scientific career. Recipient, at the age of thirty-two, of the coveted Michael Medal of the Michael Artillery Academy, and, at the age of fifty-nine, of the Bessemer Gold Medal of the British Iron and Steel Institute, his name will always stand foremost in the ranks of those interested in crystallization of metals, and especially in the Widmanstaetten structure.

The wide extent of Colonel Belaiew's research is evident from some one hundred publications dealing with such subjects as: thermoluminescence, weights and measures, high power photomicrography, origin and structure of meteorites, Damascene steel, inner structure of steels, Icelandic sagas, Vikings of the north, biographies of Osmond, Tschernoff, Henry Marion Howe, Henry LeChatelier, and so forth. The Colonel is at present Consulting Engineer for the Institut Soudiure Autogené, Paris. Truly it may be said that a chemical training builds a full, well-balanced, and fruitful life.

(Contributed by Mike A. Miller, Aluminum Company of America, New Kensington, Pennsylvania)

EDITOR'S OUTLOOK

WHAT CAN ANY ORGANIZATION DO FOR ANYONE? Professor Whitmore's presidential address at the Milwaukee meeting of the American Chemical Society raised many questions as to the future course of the organization—all of which were admittedly and intentionally left open. Answers to a great many of these questions—if not a majority of them—depend, it seems to us, on the expressed will of the membership as to the proper *nature* of the Society. Although many members might disagree with us, we have always regarded the Society as being primarily a scientific body. Yet many of its activities have not been of a strictly scientific nature in the narrowest sense of the term. There has been a tendency—and we rather think a growing tendency—for the Society to concern itself with the professional as well as with the strictly scientific aspects of chemistry. The very existence of the Division of Chemical Education (and of its official organ, the JOURNAL OF CHEMICAL EDUCATION) constitutes, in our opinion, evidence of that tendency. Is a further trend in this direction desirable? When we are reasonably agreed among ourselves upon that question we shall be in a better position to discuss whether or not this or that specific problem is properly a problem of the Society, and, if so, what the Society can and should do about it.

In the Division of Chemical Education the general sentiment would seem to be more clearly evident. There has always been an apparent disposition, not only to interpret the term education in its broadest sense, but to place few limits, other than the very liberal ones imposed by the regulations of the parent Society (and, of course, the inevitable fiscal ones), upon the scope of Division interests and activities. Therefore, when the question is raised, as it was repeatedly in one form or another at Milwaukee, "What more should the Division and its Journal do for the high-school teacher?" the question that many Division members actually begin turning over in their minds is, "What more *can* the Division do . . . .?"

We were given a public opportunity to suggest an answer to that question, but forebore to speak all that was in our mind lest some misfortune of impromptu phrasing convey our meaning imperfectly, or leave the impression of an unsympathetic attitude. Yet if the Division is to approach this question realistically and with a sincere desire to find and act upon the most fruitful answer possible, it seems necessary for someone to risk popular displeasure by pointing out that, beyond certain narrowly circumscribed limits, there is little or nothing the Division can do for high-school teachers that they are not able and willing to do for themselves.

In a certain sense the whole is sometimes greater than the sum of the parts. An assembled automobile is more than the junk-heap of its separate units. Men can often accomplish coöperatively that which would be impossible to them individually. But the assembled automobile functions because its separate parts function, and a human organization functions (when it does) for the same reason. When too many non-functioning gadgets are loaded upon an automobile (or an organization) it slows down and begins to rattle and creak, and after awhile the gadgets drop off and are lost.

"Why should high-school teachers join the Division of Chemical Education? What has the Division to offer them?" We would say that it can offer them about what a good workshop club or a good camera club can offer its members. It can offer them access to certain machinery and apparatus. It can offer them a meeting place and congenial associations. It can offer them an opportunity to exchange ideas with their peers and to seek the advice of the more experienced. It can arrange occasionally for lectures by visiting specialists on subjects of general interest. But if they mean to get their money's worth they will have to bring their own mahogany, or their own films, and their own ideas with them, and put in a little work of their own at the clubroom.

Although both the Division and the Journal invite the visiting specialist, the Division meetings and the Journal pages are primarily open forums for the *exchange* of ideas. And in order to *exchange* one must bring something to market with him. Any source of ideas, no matter how fructiferous, must be fertilized occasionally. Even a magician can't keep pitching forever unless someone tosses a ball back to him occasionally.

This is the bitter draft to which we hope to add a more palatable chaser.

To the high-school teacher himself we would say, "Do not value too lightly that which you yourself have to offer. What is old stuff to you may be news to someone whose ability and experience you have envied. It may even be that the little idea that never flourished spectacularly with you will find a more favorable host elsewhere. Think of 'Typhoid Mary'."

To the Division we would say that we do not believe that the facilities of our organization have as yet been completely inventoried. That the feasible additions to them have not been carefully estimated. That when these things have been done, it will remain for the Division to display its facilities to high-school teachers, and to show them how they can best make use of them.

Concerning these things we hope to write more later. In the meantime we earnestly invite the comments, critical and constructive, of high-school teachers and their many friends in the Division.

AMOS EATON *as a* CHEMIST

H. S. VAN KLOOSTER

Rensselaer Polytechnic Institute Troy, New York

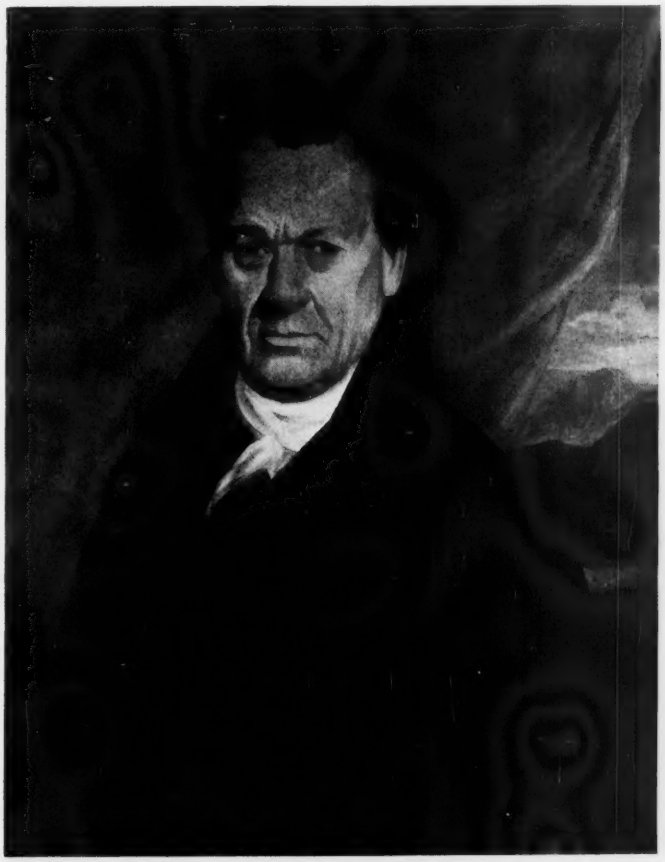
A LITTLE over three hundred years ago a lawyer, Francis Bacon (1561–1626), proclaimed that he took all knowledge for his province. Two hundred years later, Amos Eaton, "attorney and counselor-at-law" covered the whole field of natural sciences, including such diverse subjects as botany, biology, mineralogy, geology, chemistry, and physics. Today it is difficult for a chemist to keep up with the different subdivisions of this one science alone.

The closing years of the eighteenth century and the first quarter of the nineteenth century abound in examples of lawyers, interested in the pursuit of natural sciences. Avogadro (1776–1856) and Benjamin Silliman (1779–1864) are two conspicuous examples of contemporary lawyers who turned scientists.

Eaton's life story has been told by several writers (Ballard (*1*), Durfee (*2*), Nason (*3*), Perry (*4*), Ricketts (*5*), Youmans (*6*)), so that a brief outline of his career may suffice.

Born in Chatham, New York, on May 17, 1776, he went to Williams College in 1795 where he took, after the custom of those days, the prescribed course of study, including English, the classics, mathematics, surveying, natural philosophy and theology, and graduated in 1799. Though he showed a distinct predilection for the sciences, he was marked for a legal career and studied law first at Spencertown and later in New York City. There he became acquainted with David Hosack (1769–1835) and Samuel Latham Mitchill (1764–1831), both doctors by profession and professors at Columbia College, but greatly interested in botany and the natural sciences. Hosack, who had studied at Edinburgh and in England, where he had followed the lectures on geology of one of Werner's pupils, must have exerted a great influence on Eaton. From him Eaton no doubt borrowed Kirwan's "Mineralogy" which he copied from cover to cover. Hosack had many of Eaton's characteristics, being, as one of his pupils said, "a man of strong convictions, treating the various subjects connected with his professorship with boldness, impressiveness, eloquence and earnestness." Mitchill was professor of botany, chemistry, natural history, and agriculture. His aim in teaching chemistry was "to render the science subservient to agriculture, art and hygiene," objects which subsequently proved to coincide with those of Eaton in his teaching career.

Admitted to the bar in 1802, Eaton settled as a practicing attorney and land agent in Catskill. In 1810, while still a lawyer, he started a popular course of lectures on botany and prepared a small elementary treatise for the use of his hearers. This was favorably commented on by Hosack who stated that Eaton had "adopted the true system of education by properly



AMOS EATON
From a Portrait in the Dining Hall of the Institute

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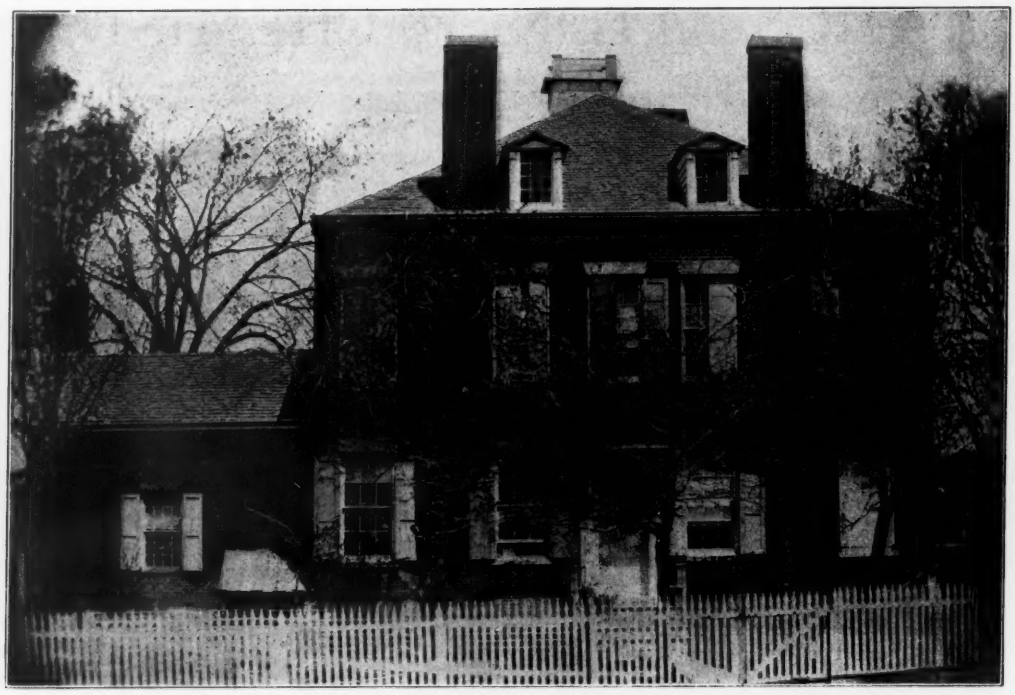


RENSSELAER SCHOOL IN 1824
Laboratories for Systematic Individual Instruction of Students in Chemistry

addressing himself to the senses and to the memory."

The period from 1810–1815 represents a dark chapter in Eaton's life. It is ignored by most biographers or briefly referred to as one in which some unfortunate experiences occurred which increased his distaste for the legal profession. As in other cases where great men have gone *per aspera ad astra*, so it was with Eaton. During these years of storm and stress he must have felt the urge to become a teacher of science. In the fall of 1815 Eaton departed for New Haven where he followed the courses in chemistry of Silliman who was a brilliant lecturer and an accomplished demonstrator, and also attended the lectures of Eli Ives on botany. With both these men Eaton was on the best of terms. The translation of Richard's "Botanical Dictionary," completed at Yale, was dedicated to Professor Ives with the statement, "that I have been governed by your opinion in all cases of doubt." From Silliman, Eaton must have learned a good deal in the way of illustrating his lectures by suitable experiments, and Silliman's translation of William Henry's "Elements of Chemistry" is constantly referred to in Eaton's writings. In the New York State Library in Albany are preserved some letters of Silliman to Eaton, while in the library of Williams College is found a collection of twenty-two letters of Eaton to Silliman written in the period 1822–1834. From New Haven Eaton started on his career as a wandering teacher. Armed with recommendations from the "generous Mitchill, whose name I feel bound ever to speak of with respect," and from Professors Silliman and Ives, Eaton embarked on an extracurricular course of lectures, mainly on botany, but partly on mineralogy and geology, before a group of students at Williams College. The success of this initial course of lectures, which resulted in another letter of recommendation, from the faculty and students of his Alma Mater, gave him further opportunities to lecture at Amherst (where Mary Lyon, the founder of Mount Holyoke, became his enthusiastic pupil), Castleton (Vermont), and a number of other places in the New England States.

In the region around Albany, New York, which is sometimes referred to as the "Capitol District," Eaton found at last the opportunity which led to the establishment of the Rensselaer School, at present known as the Rensselaer Polytechnic Institute. In 1817 De Witt Clinton, the celebrated long-time governor of New York (1817–1825), had started his campaign for cheap water transportation by proposing a canal to unite the waters of Lake Erie with the Hudson River. The success of this project depended largely upon a sound knowledge of the geology of upper New York, and Clinton, being confronted with opposition both from the legislature and from the public at large, was looking for means to carry his scheme through. It is possible that Hosack, a close friend of the governor, focused the latter's attention on Eaton, whose rising fame as an impressive lecturer was spreading rapidly in upper New York

State. In 1818, Eaton, at the special request of the governor, gave a course of lectures on geology before the members of the legislature, to imbue the lawmakers with the importance of geology in relation to water-transportation and, particularly, agriculture. It is interesting to note, in this connection, that in his first annual message to the legislature De Witt Clinton suggested that "a professorship of agriculture might also be constituted, embracing the kindred sciences of chemistry, geology, mineralogy, botany and other departments of natural history by which a complete course of agricultural education would be taught."* Is it too much to surmise that the governor had Eaton in mind when he made this recommendation? In the same year (1818) Eaton established the Troy Lyceum of Natural History (modeled on the plan of a similar institution founded in New York) "for the purpose of disseminating a knowledge of natural sciences and of other sciences." The society prospered for only a few years, due to a disastrous fire in 1820, which destroyed most of the records, museum specimens, and books.

Around 1820 appeared Eaton's first chemical publication, called "Chemical Notebook for the Country Classroom," printed privately in Troy where Eaton had settled by that time. It sold for the modest price of twenty-five cents. Though the title page does not carry the name of the author, the preface is addressed "to my own classes" and is signed A. E. This pamphlet on large-size paper and interleaved for manuscript notes, contains in twenty-four pages a brief summary of the known elementary substances and their properties, a discussion of acids, salts, vegetable and animal substances, followed by an outline of the proximate analysis of animal matter, minerals, soils, and water. Of the authors recommended for collateral reading, Eaton refers his students to Park, Accum, Gorham, Henry, Cutbush, and finally to Mrs. Marcet's "Conversations on Chemistry." Of this book which was first published about 1809 and sold by the thousand, both here and abroad, Eaton says, "It will merely serve for want of a better book. I think its day has gone by." Twelve years later he expresses his feeling more strongly by referring to the common "Catch-penny books" called "Conversations on Chemistry" which should be discarded. "They make machines of students and drones of teachers." And yet, no less an authority than Michael Faraday in one of his letters expresses his deep appreciation to the authoress (Jane Haldemand Marcet (1769–1858) the wife of a London physician) "whose book gave me my foundation in that science (chemistry)." Many other noted chemists owe their first introduction to the science of chemistry to that early, self-appointed humanizer of scientific knowledge. Professor Samuel Parsons Milliken (1864–) recalls distinctly "reading this book as a small boy, lying on the dining room floor."

* Among the De Witt Clinton papers, in the library of Columbia University there is one letter from Eaton to the governor, in which he recommends the seed of couch or quack grass on the banks of the canal for purposes of preservation.

Eaton's "Chemical Notebook" went through five editions, before it was replaced (1822) by its successor, called "Chemical Instructor." This volume of two hundred thirty-two pages is dedicated to Dr. T. Romeyn Beck and Mrs. Emma Willard. Dr. Beck was the second principal of the Albany Academy, a secondary school founded in 1813 and still in existence. Mrs. Willard had started in 1821 what was then called the Troy Female Seminary and is now known as the Emma Willard School. In part the dedication reads as follows.

"This little treatise being chiefly intended for all respectable public schools, excepting colleges, and you having been the first, in the interior of the Northern States, to introduce experimental chemistry into such schools, it appeared to be your right to approve or condemn.

"With the hope that I have not mistaken your views in relation to the method of communicating useful knowledge on a subject of so much practical utility,

I subscribe myself
Your obedient humble servant
Amos Eaton"

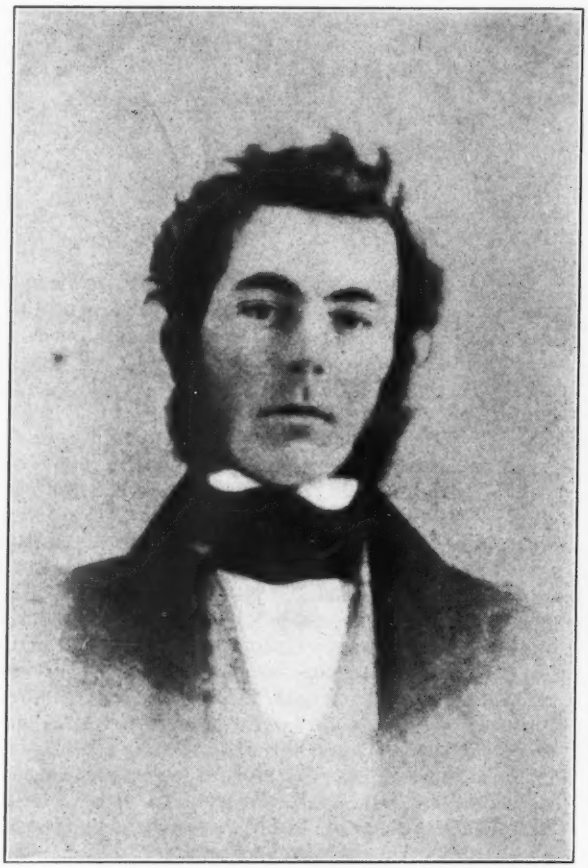
The preface is illuminating in so far as it illustrates Eaton's purpose to bring "the sublime science of chemistry within the reach of the laboring agriculturists, the industrious mechanic, and the frugal housekeeper." Experiments, meant to elucidate and explain the application of every practical principle of the science, were selected in such a way that a minimum of expense was involved. Originally starting out with apparatus and chemicals costing one hundred fifty dollars, Eaton had finally managed to give courses with apparatus costing only fifty dollars, with which about five hundred experiments were shown. The cost for a course of thirty lectures was stated as four dollars, and for a shorter course of twenty lectures the fee was three dollars.

In concluding the preface, the author says, "This book, as far as it goes, may guide the infant steps of him who calculates to become a giant in chemistry." This expectation has never been fulfilled. Going over the records of eighteen years, during which period Eaton was the guiding genius of the Rensselaer School, we find in a list of four hundred pupils barely a dozen chemists, of whom only three, *viz.*, James Curtis Booth, Eben Norton Horsford, and Robert Peter have left a mark in their chosen profession. Eaton's main accomplishments were, no doubt, in the field of geology and he may be rightly considered one of the founders of American geology. His pupils, Cook, Emmons, Hall, Houghton, Sager, and Tuomey were all noted geologists. James Hall, who taught chemistry in his early days at the Rensselaer School, was Eaton's most brilliant student and became a scientist of world-wide repute.

Eaton's "Chemical Instructor" follows on the whole the outline of English texts quoted by him in the preface, particularly that of Brande as edited by MacNeven. Eaton shows himself a firm believer in the experimental side of chemistry and relegates the theoretical aspects to half a dozen pages at the end of his texts. This is likewise evident from the following statements.

"In all cases the curiosity of the student should be excited by experiments and demonstrations, addressed to the senses before he is directed to study elementary principles. A succession of experiments accurately performed and riveted in the memory by reference to familiar applications, will furnish students with a passport to the highest orders of reading and reflection.

"In all cases the memory seems to be the faculty most easily jaded down and is the first to refuse to perform its part. Therefore the senses should be put in requisition in all possible cases; and the imagination must be chastened in aid of the senses. Experiments and specimens should be perpetually before the students' eyes; and well-selected anecdotes should elicit fancy." A few illustrations of Eaton's method of approach follow. In discussing sulfuretted hydrogen, it is brought out ". . .that ladies who paint their faces with a cosmetic whose base is bismuth or other metal, often become tawny on approaching an old dock or sewer." On the subject of adsorption by charcoal Eaton remarks, "There is not an experiment which explains more of the practical principles of agriculture and domestic economy than this. Tooth powder from heated charcoal is the best of all known substances to preserve the teeth from decay." Arsenic is introduced with these words, "Let the busy tongues of two or three sage matrons set up the cry of arsenic, and twenty wise sons of Aesculapius will find any quantity of it in a stomach where nothing but the mother's milk has ever passed the subject's lips. Many an honest man has suffered death through the affected wisdom of physicians and scientific quackery of the bench and bar." This statement, coming from a man who was married four times and counted many noted women (Mary Lyon, Laura Johnson, Mrs. Lincoln Phelps, Mrs. Willard) and numerous physicians among his pupils, must have met with strong protests from different quarters. In the second and subsequent editions it is omitted, and the reader is referred to the tests for arsenic given by Dr. R. T. Beck in his "Medical Jurisprudence" with the added observation that ". . . no one should proceed to an examination without accompanying every step with a similar collateral experiment upon a specimen known to be arsenic."



JAMES HALL, 1843
(From a daguerreotype)

The analysis of soils and mineral waters was a subject to which Eaton devoted considerable time during the years 1820 and 1821. Here he showed himself an investigator of no mean ability. Thus he advises us to ". . .always institute collateral experiments upon known substances which are similar to those for which you are searching. In doing this, make use of very minute portions because large quantities may alter the appearance."

The synthesis of ammonia from the elements, which has occupied the minds of the foremost chemists for over a hundred years, is the subject of one of Eaton's experiments. A flask is filled with nitrogen and small balls of pulverized iron powder moistened with water, are dropped into the flask. After a considerable time hydrogen is produced which in the "evanescent state" unites nitrogen and forms ammonia. Eaton adds in a postscript, "I have sometimes failed in this experiment without being able to assign a reason for this failure." In the later editions this experiment is still mentioned, but ". . . a much better method is to decompose ammonia by passing it through a hot iron tube." One very curious illustration mentioned by Eaton is the preparation of the so-called black oxide of mercury. The author found that more than a pound of mercury placed in a quart stone jug was converted into the black oxide when he traveled over a rough dirt road from Pittsfield, Massachusetts, to Troy, a distance of thirty-five miles.

In his theoretical outlook Eaton follows in the steps of Mitchill by upholding the ideas of Lavoisier, Berthollet, and most of their fellow countrymen. He states, for example, at one place, "I have treated caloric as a material fluid which I suppose I may venture to do since Professor Hare has had the impudence to demonstrate

the absurdity of Davy's vibratory theory." Davy is the butt of repeated attacks, for Eaton never could bring himself to believe that chlorine (the so-called oxy-muriatic acid) is an element. He is particularly incensed against "those endless compounds with chlorine and iodine which can never profit the scholar nor the practical man." In a letter to Silliman, in which he refers to his "Chemical Instructor" ("You will find a few new things in it or new methods of simplifying old things") he hopes that Silliman will give the largest space to the most common and most useful subjects. "Surely those works are very absurd which, like Davy and his descendants, represent the various idle combinations as of equal importance with those facts and principles upon [which] life depends."

The "Chemical Instructor" must have been a great favorite with students and teachers, as is indicated by some letters received by Eaton, abstracts of which are printed in the preface to the third edition (1828) (7). The second edition appeared in 1826, while the final (fourth) edition, published in Troy, is dated 1833. It contains three hundred twenty-four pages, as against two hundred thirty-two in the original edition.

How large a share Eaton had in the establishment of the Rensselaer School will probably never be fully known, on account of the few available Van Rensselaer documents. Judging from Eaton's letters and writings, the initiative was his, and he may well be considered the moving spirit in the founding of the school that bears the name of the donor of the necessary funds.

Stephen Van Rensselaer (1764–1839) the eighth and last "Patroon" was a public-spirited and enlightened man of means, a graduate of Harvard, a member of the State Legislature, and later a Congressman. As a member of the Erie Canal Commission, from the start, he had employed Eaton on several occasions to make geological surveys. When convinced of the utility of the school project he undoubtedly consented to furnish the means to establish the school and maintain it during the first precarious years of its existence. Yet he always insisted on being consulted in all matters pertaining to the activities of the beneficiaries of his generosity. This comes out very clearly in a letter from Eaton to Silliman in which he says, "I must consult Mr. V. R. But I am almost sure he will consent [to pay the expense]. I shall wait for your answer before I consult him for reasons of a peculiar kind which apply to his peculiarities." That Eaton had the establishment of a school of his own in mind may be inferred from the dedication of his "Chemical Instructor" to two successful school principals. Even more significant is the statement, ". . . every city, large village or populous district ought to be too liberal to depend on itinerant lecturers. They should support permanent teachers of the right kind." There are also a few pertinent items of interest which the writer found in a voluminous compendium that was a part of Eaton's original library. In the "Gazetteer of the State of New York," published in 1824 and compiled in the years 1820–1824, the editor (no doubt, a good friend of Eaton) in speaking of Troy's Lyceum of Natural History, calls Eaton ". . .one of the most useful men of the City, a learned and zealous cultivator of the Natural Sciences." He also states (page 605), "We have fewer facilities for acquiring a knowledge of the Natural Sciences than we ought to have," and on page 524 he says, "Troy wants an Academy for males." Frequent mention is made of the "Patroon," and on page 502 the editor confides, "It has often occurred to me that this gentleman, inheriting an annual income of something like $100,000, might do well to establish a Pattern Farm, at his own expense, for the benefit of his estates, his tenants and the community. He is able enough to do it and liberal enough, and I can only suppose the thought has not occurred to him." Evidently there were, even in those early days, plenty of men with new ideas, anxious to dispose of other people's money. It is a tribute to the patroon's generosity that the term "at his [own] expense" is encountered in several letters, books, and documents. In one of Eaton's letters, written in 1830, it is said that the patroon had up to that time spent more than $18,000 for the school. The new school, providing mainly instruction in Natural Sciences was originally planned on a one-year basis and did not acquire college status until 1862 when degrees were given only after four years of attendance at the Institute.

Although the school was officially established by a letter of the patroon dated November 5, 1824, regular instruction did not get under way until the spring of 1825. It appears that Eaton also had a hand in the selection of the president. In a short note (undated) to the patroon, Eaton says, "The annual meeting of the board did some business. Messrs. Dickenson and Parmelee were appointed to confer with Mr. V. R. in relation to the person to be selected. I suppose it should be some respectable clergyman. There seems to be no prominent character. Should Dr. Nott accept?" The first respectable clergyman to be chosen president was the Rev. Samuel Blatchford, who died in 1828. The Rev. John Chester, appointed in 1828, died within six months and was succeeded by Dr. Eliphalet Nott in 1829. Dr. Nott, who was at that time also president of Union College, resigned in 1845.

The school was incorporated on March 21, 1826. The preamble of the act, signed by Governor De Witt Clinton, contains the following statements.

"Whereas the Honorable Stephen Van Rensselaer has procured suitable buildings in the City of Troy in Rensselaer County and has there set up a School and at his own expense has furnished the same with a scientific library, chemical and philosophical apparatus, instruments for teaching and surveying and other branches of practical mathematics which are useful to the agriculturist, the machinist and to other artists, and furnished separate and commodious rooms for instruction in natural philosophy, natural history, the common operation of chemicals, and an assay room, for the analysis of soils, manures, minerals, and animal and vegetable matter with the application of these departments of

science to agriculture, domestic economy and the arts....."

Although it seems likely that Clinton took an active part in the organization of the school, because it embodied so many of his ideas and also because he was on friendly terms with the Patroon and Eaton, there is no positive proof of this inference.

With regard to the laboratories *for student use*, started by Eaton, it has been said by the late President Ricketts in a pamphlet issued in 1933 (*8*) that they were the first to be created in any country, setting the date some time in 1824. Quite recently Dr. Simon Flexner (*9*) made the statement, "In 1825 in Gieszen the important step [of laboratory instruction] was taken when Liebig's laboratory was opened. It was Alexander von Humboldt, the insatiable traveller, who was responsible for this great innovation; he secured entrance for Liebig in all private laboratories of France, and it was Humboldt who brought Liebig to the little University of Gieszen."

Going over the available records it appears that Eaton and Liebig started their laboratories *simultaneously*. There are two letters of Eaton preserved which speak for themselves. On February 4, 1825, Eaton wrote to Alanson Douglas, Esq., ". . . to notify the Insurance Company of Troy that the Building usually called the Old-Bank Place is now fitted up with a chemical air furnace, nearly upon Dr. Black's method with the pipe passing through the upper ceiling and entering the chimney in the garret." In another letter dated October, 1825, he says, ". . .the following additions, repairs and various works are now in progress. Two rooms for students in the south part of the upper loft, two additional chemical laboratories in the north part of the upper loft, one with a forge and essaying furnace."

This description checks with what Eaton's pupil, Douglass Houghton, wrote in a letter dated April 25, 1829. "I will first name the rooms contained in the building independent of the private rooms. They are six: reading room which contains a fine library in which examinations and criticisms are held. The Assay Room with all the apparatus necessary for assaying ores and performing those experiments which require the aid of a high heat. Laboratories numbers one and two which contain all the apparatus appertaining to pneumatic chemistry and also the apparatus for performing those experiments which do not require a high heat. Philosophy Room which contains a fine set of philosophical apparatus. Natural History Room which contains Botanical, Zoölogical and Geological specimens."

With regard to the establishment of Liebig's laboratory, we find that on July 20, 1824, the ministry of the Grand-Duchy of Hesse authorized the use of the vacant building adjoining the police barracks as a chemical laboratory. Liebig began his lectures on December 11, 1824, and the laboratory was opened some time in 1825.

This remarkable coincidence is possibly not wholly fortuitous. If Liebig got his stimulus from Humboldt, it is not at all improbable that Eaton, too, was influenced by the great globe-trotter's ideas on education. Eaton, in his own way, was a hero-worshipper: one son was named for Linnaeus, another for Cuvier, and his youngest son (by his fourth wife) born in 1829, was named after Humboldt.

Although established at the same time, the two laboratories served two entirely different purposes. Eaton intended to teach his students the rudiments of experimental chemistry, a task that had already been successfully accomplished previously by other teachers of chemistry. Dr. C. A. Browne, in his biography of Fredrick Accum (*10*), pointed out that several American chemists (Gorham, Dana, Silliman, Peck, and others) had acquired their chemical technic in Accum's laboratory long before Eaton's time. The distinction of having established the *first laboratory in the world* for the regular instruction of students in practical chemistry belongs, however, to the great Russian physical chemist, Lomonosov (1711–1765) who built his laboratory at St. Petersburg in 1748 (*11*). It is well known that Liebig's laboratory was meant to be a research center for advanced students of chemistry. As a matter of fact, one of Eaton's own pupils, Horsford, of the class of 1838, spent two years (from 1844 until 1846) in Liebig's laboratory. Comparing the two laboratories, Horsford, in 1874, (*12*) said, "It was a source of pride and satisfaction to me when it was my fortune to enter Liebig's laboratory as a pupil, to find that the methods pursued under the guidance of that great teacher were, in many respects, the methods I had been familiar with in the Rensselaer Institute, carried out with the ampler facilities furnished by Government, but essentially the same in conception, in fitness, in certainty of result."

Much has been written about the "Rensselaerian" system of teaching science, introduced by Eaton and, with some modifications, continued to the present time. This intensive lecture-recitation-laboratory system of education has been described in various letters and circulars, but is most graphically expressed in two letters of Eaton, addressed to his friend, Silliman. On March 15, Eaton wrote, "I have, with the consent of the Patroon, undertaken to exercise forty members of the Troy Mechanics' Society in the Rensselaerian plan. That is, we hear ten of them lecture in experimental chemistry in our simple way, every evening. We hear them in two laboratories (five in each). They are all to perform experiments with their own hands in our usual way. I will let you know how we succeed." Another letter, dated April 5, 1826, contains the following humorous statement, "You know we treat science here as the Yankees do their money-making pursuits. That is, when one makes brooms, all make brooms, when one makes buttons, all make buttons, etc. Now we are *all* driving at zoölogy. Not a bug, snail, lizzard, toad or snake escapes the persecutions of the young Trojans and Albanians."

Eaton was also an early organizer of student trips for the study of botany, geology, mineralogy, and perhaps agricultural chemistry. Two letters, both addressed to Silas Wright, comptroller of New York, regarding trips with the canal boats "William Penn" and

"Surprise," are preserved in the Institute Library. Rafinesque, the brilliant but erratic naturalist, accompanied Eaton at some time on one of his annual excursions. These trips are still a feature of the Institute activities and are now taken, by train or auto, during a specified period around Easter time which is designated as "Trip Week."

Eaton's devotion to certain famous men of science which permeates all his writings, to whatever field of endeavor he applied himself, was more than counterbalanced by the extreme dislikes he expressed for those scientists of whom he did not approve. Overlooking the fact that he himself is not free from partisanship, he makes this extraordinary comment, "The authority of names is often a great impediment to the progress of knowledge. If accident has given charm to the name, Davy or De Candolle, all must stand aloof in silence, or twine about their footstools as parasitic slaves." More than seventy years later, another chemist, Sir William Ramsay, made the same remark when he said, "It is regrettable, but perhaps unavoidable, that the appearance of a great man is followed by a period of stagnation. . . . ."

In speaking of American contemporary scientists, Eaton is particularly scornful of his Philadelphia colleague, Professor Robert Hare. In writing to Silliman, Eaton states, "Cortland V. R. [a son of the Patroon and pupil of Eaton] says, many think you too servile a follower of Professor Hare and have too much of him in the Journal. Don't call this gossiping. I tell you all and am willing to be the goat." Later (January 24, 1832) he comes back with the remark, "I am not a male gossip, but you [meaning Silliman] are a large mark to shoot at and ought to know when to dodge, when to use the shield and when to return the shot." Introducing himself and his co-workers as "agents of General Stephen Van Rensselaer" Eaton mentions in 1833 in the preface to the fourth edition of his "Chemical Instructor," "Most laboratories in this country have become simplified since 1824. Some do, and some do not acknowledge that they are indebted to the eight years of trials made by Mr. Van Rensselaer's agents, at his expense. But the truth will, at last, be known. Professor Hare is the inventor of most of the curious apparatus and Mr. Van Rensselaer's agents of the cheap and simple, hitherto in use in North America." Eaton's unbounded enthusiasm and loyal devotion do not always make for accuracy and are no doubt conducive to exaggeration and overstatement.

At times irascible and easily aroused, Eaton is not always fair even to those in his immediate environment. Of Dr. T. Romeyn Beck whose aid and encouragement he frequently solicited Eaton said (in 1829), "They [meaning Dr. Beck and his three brothers, D. R. Beck, Lewis C., and John B.] are truly an united band of brothers, undoubtedly ambitious, cool, calculating and deliberate." Of Mrs. Willard, to whom the first edition of the "Chemical Instructor" was dedicated, he wrote, about the same time, in a letter to Silliman, "Mrs. Willard has been harassing me these two years about the kitchen chemistry. She thinks she could write a good one and is asking me for suitable books to aid her. My repeated reply is in my usual abrupt manner with her. I tell her she is totally incompetent and that I can direct her to nothing but detached scraps of various authors." And thus, blamed (or praised) be Eaton, we have no Willard "Kitchen Chemistry" to compare with Accum's Culinary Chemistry (1821) or any of the modern "Chemistry and Cookery" texts with which the female youth of today is being educated.

Eaton must have lost his lively interest in chemistry soon after the fourth edition of his chemistry text appeared. The school catalog of 1835 mentions the appointment of James Hall, then a young man of twenty-four as professor of chemistry, while Eaton continued, until his death (in 1842) as professor of botany and geology. These glimpses of the chemical contributions of Eaton to the natural sciences of a hundred years ago, may leave the reader with some impression of the versatile nature of an extraordinary man whose fame is perpetuated in the institution of which he was the spiritual, if not the actual, founder.

While Liebig's laboratory has been preserved for posterity as a mecca for present and future students of the history of chemistry in Europe, Eaton's laboratory was demolished long ago and nothing tangible remains but a few score of books that once belonged to Eaton and are now kept in the Institute library, erected in 1926 and named after its first professor of natural science.

The picture that accompanies this article is a reproduction from a portrait in the Dining Hall of the Institute and represents Eaton in middle age (around forty to forty-five). It differs considerably from the better-known picture, *viz.*, a steel engraving by A. H. Ritchie, made from the portrait by Abel Buell Moore in the Trustees' room of the Institute. The picture by Moore was taken in the summer of 1841 at the request of Eaton's students. Eaton's niece, Mary Halsey Thomas, stated, in a letter, that it was an excellent likeness of Uncle Amos.

The renewed interest in Eaton, as witness the recent article on "Amos Eaton, Naturalist," by Professor W. M. Smallwood, of Syracuse University (*13*), is also expressed in the extensive investigations of Miss Ethel McAllister which, it is hoped, may lead, in the near future, to the publication of a "Life and Letters of Amos Eaton," that will take its place alongside the biographies of other noted contemporary educators.

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QUANTITATIVE EXPERIMENTS *in the* FIRST YEAR CHEMISTRY COURSE*

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FOR a number of years at Oberlin College, we have kept a record of the results from the quantitative experiments reported by our beginning chemistry students. At the same time we have recorded the previous preparation of our students in chemistry and physics. Recently we have attempted to find a correlation between the previous preparation of students and their accuracy in quantitative results. It seemed reasonable to us that students prepared in high-school chemistry and physics should get better results, in the first few quantitative experiments, and that any variation due to differences in preparation might disappear in the later experiments after the fundamental skills were acquired by all students. We were surprised, however, to find that, so far as the reported results are concerned, there are no significant differences in accuracy between those who presented both high-school chemistry and physics, chemistry only, physics only, or neither.

Our students begin their quantitative experiments immediately after all the class has had instruction in the use of the analytical balance, about two weeks after the beginning of school. The first experiment, to test the law of definite composition, is performed in duplicate by converting pure silver to silver chloride. Each student weighs two pieces of pure silver (about 0.5 g.) and two evaporating dishes, dissolves the silver in nitric acid, adds HCl to precipitate the chloride, and then evaporates to dryness over a water bath. Then he heats the dishes to the fusion point of AgCl, cools, and weighs them. All the students are, of course, subject to the errors inherent in the method, such as those caused by the presence of non-volatile matter in the acids used; and the mean percentage of silver in the actual results does lie slightly below the theoretical percentage. In other respects the experiment is satisfactory. The silver chloride is stable up to temperatures above its fusion point, so that weights on a dish may be reproduced on reheating. In addition there are possible errors due to faulty weighing, calculation, and manipulation. I expected students with previous training to excell in these respects, but our analysis of the students' results showed no such selection.

Our list of quantitative experiments includes the testing of Boyle's Law, the analysis of potassium chlorate for oxygen, the determination of the equivalent weight of magnesium through the formation of magnesium oxide from magnesium, the securing of the equivalent weight of zinc by measuring the volume of hydrogen displaced by a weighed piece of zinc, a comparison of valences by measuring the volume of hydrogen displaced by milligram-atomic weights of sodium, magnesium, and aluminum, and the analysis of $BaCl_2 \cdot 2H_2O$ for water of crystallization.

Here is a list of quantitative experiments requiring a great variety of technics and calculations, yet the results we have studied do not warrant attributing any superiority of results to those students who have had high-school chemistry. I had observed that students who had taken excellent high-school courses, and with a good knowledge of chemical theory frequently re-

* Presented before the Division of Chemical Education at the ninety-third meeting of the A. C. S., Chapel Hill, N. C., April 14, 1937.

ported mediocre results for the quantitative work, but even so I was not prepared for the conclusion that these students would show no superiority over those with no preparation. My own interpretation of these results is as follows.

Almost none of our students has had previous training in quantitative technic, and apparently none of the other preparation of the students in high-school chemistry enables them to avoid the beginner's errors in analysis. The analytical balance is new to them, and some of them record the weights wrongly. The student with high-school chemistry appears just as likely to set a hot weighed evaporating dish on a dirty desk top so that it gains weight, as does the new student, and the student who has had high-school chemistry appears just as likely to make errors in calculation of results from the data, as one who has no knowledge of the subject.

If our observations have general validity, a high-school course in chemistry must be justified on grounds other than its preparation of the students for quantitative experiments.

The student with a background of high-school chemistry does work *faster*, and he is more likely to finish all the quantitative experiments, but his reported results are *not more accurate*.

The conditions under which the students work may have some bearing on the results. Weighings are made on analytical balances. The use of good balances by the students is fully justified by the amount of quantitative technic acquired by the students. In the experiment on the hydration of barium chloride for example, more than seventy per cent. of the students report experimental values within two per cent. of the theoretical value. To obtain these values differences in the weights of the crucible before and after heating must be accurate to less than 6 mg. Again, in weighing out milligram-atomic weights of metals for the valence experiment, good balances are necessary. Several teachers have suggested that analytical balances are wasted on first-year students, but in my opinion the only valid reason for not having them, if quantitative work is to be done, is lack of money for equipping the laboratory with them. In our classes three students in a section are assigned to a balance but no time need be lost for a student can perform non-quantitative experiments if his balance is in use. Each student is given a half hour's instruction, and one-half to one hour's practice before he uses a balance. In our experience even the students who have had college physics need instruction in good balance technic.

The question of the reliability of the results reported by the students needs some attention. We are assuming that the results turned in by the students are substantially honest results. We have a reasonable degree of confidence in the results because it is our practice to accept any result a student reports. There are no official limits within which the experimental results must fall before they are accepted. Grades on the quantitative work are based primarily on the understanding a student shows of his experiment and not on the numerical value of his reported results. This appears to be a departure from general high-school practice for at the beginning of each year we have a number of inquiries concerning the maximum and minimum results accepted. There is the implication that a student should be told what results he must get before he starts to work.

If errors in calculation are found in the student's work, of course we ask him to make the proper recalculations. In our experience many of the unreasonable results are due to improper recording or reading of the weights, and most of these errors occur in the early experiments. In about half of these cases, we can trace the error by a careful inspection of the original data recorded by the student. Of course, the original data are necessary for this kind of check, and therein lies a difficulty. It requires an intensive drive to persuade (or force) the students to record their original observations in some permanent form. All their high-school training seems to be against it. Their unrestrained practice unvariably is to record data on scrap paper until they see "whether the results come out right" and then to copy them neatly into the laboratory notebook. In Oberlin we feel that a student's notebook should be a record of his actual work, that a record of mistakes may be instructive to an intelligent student and that the scientific spirit is not developed if the student starts an experiment with the preconceived idea of securing a value the teacher will accept. We have had to give up our attempt to force all the students to record all data directly in their notebooks, for all high schools seem to be against us, but we do insist that the student who objects to the former procedure, records all his original data in a small bound five-cent notebook which he may keep in his own desk.

When a student presents poor results not directly attributable to errors in calculation or weighing, we ask him to review his procedure with a view to explaining his own results. Often the student is fully conscious of the mistake after it occurs. In any case we feel that a student learns more by a sympathetic analysis of his failures than by being required to repeat (or recalculate) his work. In practice some of the students with poor results do repeat their experiments but they do so entirely of their own volition.

The quantitative experiments enable us to do one more thing. Our students, almost without exception, do not understand the relation between the number of significant figures in a datum and the number in the result calculated from this datum. Even our bright students confuse ***number of significant figures*** with ***decimal places***. Each student's quantitative result gives us an opportunity to teach him to judge the degree of precision of his own data just as our experiments involving gas law and vapor pressure corrections enable us to put meaning into these gas law calculations.

We feel that the quantitative experiments are an important part of our course in general chemistry, and

we are not dissuaded from this belief because we find we are presenting something new to all our students. Perhaps the quantitative experiments serve a special purpose in persuading the bright students of high-school chemistry that a college course still has something new to offer them.

TRAINING CHEMISTRY TEACHERS *in* PENNSYLVANIA'S TEACHERS COLLEGES*

JOHN ARTHUR LEWIS

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A YEAR ago a very splendid report† was given this meeting, having to do with the training of high-school chemistry teachers. With the rapid development of survey, orientation, and integrated courses, with emphasis on more or less hazy and immeasurable values, and with a clamor for functional teaching, we hardly know what to teach our prospective high-school teachers. We almost overlook the fact that it is not only wholesome for the teacher to know the fundamentals of chemistry, but it is, in fact, necessary—just as it was twenty years ago. As Fitzpatrick says, "Our teachers know so many things which are not true." Wray, of Pennsylvania State College, has shown that we are teaching much that is unnecessary and leaving untaught much that is greatly needed.

In Pennsylvania we are trying to keep our feet on the ground and our heads clear. Entirely new curricula are proposed for Pennsylvania's State Teachers Colleges, taking effect in September, 1937. A basic two-year program is proposed for all students—elementary, secondary, and special. This is provided with the idea of giving all young folks of college age a broad, cultural two-year post high-school education.

Such students as show suitable ability are then to be admitted to two years of specialized and professional training leading to a bachelor's degree, and equipping them to teach. Provision will be made during the first two years for the election of special courses leading to such fields as chemistry, history, mathematics, and so on, so that the student may have at least three, if not four years, of work in the field of his special interest.

A brief summary of the work of the first two years of the basic curriculum is—English (including literature) fifteen hours' credit, geography, six, health education, four, education and psychology, eight, social science, six, biological science, six, physical science, six, music and art, four, and elective, ten.

During the second two years are included teaching, conference, and selection of materials, fifteen, American government and law, four, education and psychology, eleven, and electives, thirty-one. The basic curriculum is to be taken by all students; the following two years, summarized above, applies to the secondary group only.

The chemistry courses listed as "required" for those who specialize in chemistry are general inorganic, eight credits, analytical, six, and organic, six.

Provision is made for additional electives in chemistry, the nature and extent of which will depend somewhat upon the local conditions. This chemistry program is essentially the same as the one recommended by a conference of all of the science teachers in the state teachers colleges. It is believed that it will give adequate preparation for a high-school teacher of chemistry and at the same time will give him sufficient background with which to pursue graduate work.

It is one thing to attempt to give students adequate preparation—it is another thing to get our state departments to back us up, although I must say that our own department has been fairly good in that respect.

At present we have a state certificate in "chemistry" granted upon completion of eighteen credits in chemistry. But we also have a state certificate in "science" which permits its holder to teach any and all science courses. This certificate is granted upon completion of eighteen credits, distributed as follows: physical science, nine, including three in physics and three in chemistry; biological science, nine, including three in botany and three in zoölogy. In other words, the

* Presented before the Division of Chemical Education at the ninety-third meeting of the A. C. S., Chapel Hill, N. C., April 13, 1937.

† Committee Report, "High school teaching of chemistry," *Ind. Eng. Chem., News Ed.*, 28, 147 (Apr. 20, 1936).

holder of this certificate may teach chemistry in any high school in the state if he has completed one semester of it in college (providing, of course, that he has fifteen credits in biology and physics). This is decidedly weak, and we are hoping that with the adoption of the new teachers college program the certification requirements will be revised. In fact, we have been assured that they will.

Certification revision is being urged by the Teachers College science teachers, by the Pennsylvania Academy of Science, and by the Conference on the Education of Teachers in Science. These three groups are almost unanimous in their recommendations, which are well stated in a report given by Dr. Ellis Haworth of Wilson Teachers College, Washington, D. C. This report was adopted by the Conference on the Education of Teachers in Science at their meeting at Montclair, New Jersey, last November, and a copy has been sent to our state department. I quote from the report.

1. "The Candidate should have a bachelor's degree from an accredited four year college. (Teachers college, Arts college, or University.)

2. "The candidate should have thorough preparation in one field of specialization, sufficiently intensive and extensive to make it possible for him to take up graduate work without appreciable loss of time.

3. "The candidate should have included in his program courses in English and the social studies such as will insure his ability to serve successfully as a professionally trained teacher.

4. "The candidate should have included in his program one or more minor fields in which he can teach in case of need.

5. "The candidate should have completed satisfactorily a series of courses in education representing a definite program of preparation for teaching in the secondary schools. Included in this program there should be two courses, one in observation and practice teaching of science in the secondary schools, and the other in the materials, methods, and technics of teaching science in the secondary schools. These two courses should be given, preferably, by the science department of the training institution.

6. "Certificates shall be issued to teach specific subject fields, such as general science, biology, chemistry, or physics; a general certificate to teach science shall be granted subject to the provision of the completion of I, *a*, *b*, and *c*, below.

7. "That no certificate in a specific subject field be granted and that no teacher be assigned to teach in that subject field, unless the prospective teacher has a minimum of at least twelve semester hours of courses on the college level in that field.

8. "That credits for survey courses (or integrated courses) in science shall be allowed if accompanied by additional courses in allied, specialized science fields.

"To put into effect the general principles outlined above, the Committee recommends the following specific requirements to teach the subjects indicated:

I. (*a*) Biology or chemistry or physics (as a major field) at least twenty-four semester hours
(*b*) Biology or chemistry or physics (as a minor field) at least twelve semester hours
(No one may be certified to teach biology or chemistry or physics who has not completed at least twelve semester hours in that field in college. In addition he must have completed a major of at least twenty-four semester hours in some field.)
(*c*) General science (in junior high school) at least thirty semester hours must be completed in science courses in college with at least six semester hours each in general biology, general chemistry, and general physics, plus a course or courses in earth science and astronomy

II. Education and psychology (including observation and practice teaching, and methods and technics or teaching science in secondary schools) twenty-four semester hours

III. English and literature nine semester hours

IV. Social Studies nine semester hours

V. Free Electives variable

Courses in physical education shall be in addition to above."

I have no intention of arguing in this paper for or against either our proposed curriculum or the recommendations for certification. I present this with the hope of receiving the benefit of your reactions. However, there are two questions which I wish to add for your consideration. In the first place, our graduates seldom get positions in which they teach only one science. These jobs are found in larger schools, schools which pay larger salaries and demand experience.

R. D. Reed, of Montclair, New Jersey, reported in a study of the range of subjects taught by science teachers in New Jersey, that one hundred thirty-six teachers were teaching only general science, or chemistry, or biology or physics, but that three hundred seventy teachers were teaching a total of one hundred fifteen combinations of sciences with sciences or sciences with non-science subjects. While this is a deplorable condition, still it is a fact which we must face.

Is it a possibility that we may require such intensive specialization in science that our graduates will not have sufficient equipment—that is, sufficient spread of subject matter—to get the jobs which will be open to them? Are we in danger of swinging from one extreme to the other? Has the time come for us to urge a fifth year of training? By taking a fifth year, a student would be able to get a wider spread during his first four years and a more intensive preparation during his fifth. Thus he would be better qualified for the generalized type of job open to beginners and at the same time be prepared for the higher salaried promotion.

We are interested in receiving comments upon our proposed program in Pennsylvania, as well as upon the Certification Report and the proposed fifth year of study.

On CERTAIN RELATIONS *between* CHEMISTRY *and* GEOMETRY

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CHEMICAL theory is connected with geometry in various ways, but only one of the points of contact between these two sciences will here be considered. The particular relation in question has been a subject of somewhat fanciful speculation since early times; but it first came prominently to the attention of practical chemists about 1825, following the discovery of isomerism. Up to that time molecular formulas such as H_2SO_4 or C_2H_6O or C_4H_{10} had been supposed uniquely to identify the respective compounds to which they referred. In fact, so firmly was this notion ingrained in the minds of most chemists that they were loath to admit that two compounds as clearly distinct as ethyl alcohol and dimethyl ether could have the same molecular formula C_2H_6O. Nevertheless, the truth would out. It was finally conceded that a molecular formula does not in general uniquely define a pure substance and that, when two or more isomers corresponding to a single molecular formula are known, this molecular formula by itself tells very little about the reactions of the compounds in question.

Hence chemists were obliged to look for a more detailed method of formulation. In this search, they were guided exclusively by a proposal which came from Berzelius. About 1830 he suggested that the differences between isomers be accounted for by the assumption that they differed in the spatial (*i. e.*, geometrical) arrangement of the atoms within the various isomeric molecules. That chemists have been guided exclusively by this suggestion appears from the fact that up to the present no one seems to have asked: Must isomerism necessarily be a matter of intramolecular spatial arrangement? Is no other type of explanation possible? This question is here raised not with the intention of giving an answer, but in order to call attention to the fact that developments in the field to be discussed have from the start depended largely on intuition, and have owed little to careful logical analysis.

However, since I can offer no alternative proposal, it will here be necessary to do what chemists have always done—that is to accept the suggestion of Berzelius. The next step is to trace the development of his idea, for between the adoption of the principle that isomerism is due to difference in intramolecular arrangement, and the discovery of a type of arrangement competent to account for the observed numbers of isomers there is a wide interval. The history of organic chemistry between 1830 and 1855 might be epitomized as a stumbling search for such a satisfactory type of arrangement. At last the clouds broke. It was the structural theory usually associated with the name of Kekulé which first shed light upon the question up to that time so obscure. This theory is the subject of the present paper.

The theme is well worthy of close attention, for the Kekulé theory is one of the most remarkable generalizations which has ever emanated from the human mind. It would be hard to find any other theory invented since Newton's day which has arranged and clarified so large and so intricate a set of phenomena as the one covered by the chemical structural theory. As is well known, this theory in the form originally proposed has not stood all the tests of experience. It has, therefore, been modified by the theory of tautomerism, the stereochemical ideas of van't Hoff, the Baeyer strain theory and various other less classic notions. But all these later developments are correction factors of the second order. Emphatically, they are slight modifications introduced into the main theory in order to bring it into better accord with observed facts. By and large, they leave unchanged the important features of the main scheme such as the quadrivalence of carbon, the existence of multiple valence bonds, and so forth. Hence these later additions will be here neglected and attention confined to the structural theory in its original or primitive form. That is still the cornerstone for the great edifice of organic chemical theory.

Since nothing but the structural theory is to be examined, the field of investigation is sharply limited. There is no necessity of inquiring what atoms or molecules *are*, or what *are* the relations between their various parts. Attention may be centered exclusively on much narrower questions. What does *the structural theory assume* about the nature of atoms and molecules? What does the success of *this theory prove* about the relations between their parts? That is, instead of discussing all that is known about the constitution of matter, only what is known by virtue of the structural theory need be considered. All information obtained (or thought to be obtained) from other sources may be disregarded.

But, although attention is to be centered on the structural theory, it should not be forgotten that this theory, like most scientific generalizations, is not perfectly inde-

pendent of all other hypotheses. Clearly, a structural theory anything like the one now in general use is an impossibility unless it is preceded by an atomic-molecular hypothesis. That hypothesis in turn was never more than an armchair speculation until chemists had proved the law of the conservation of mass. And so one may go back almost indefinitely. These prior assumptions which underlie the structural theory must be accepted if that theory is to be treated intelligently. On the other hand, the subsidiary theories which, following the structural theory, are based upon it, and the collateral theories which, though resting in part on the same foundation which supports the structural theory, are independent of it, may be ruled out of consideration.

The structural formula which any organic compound is assumed to possess is expressed in a notation due chiefly to Crum-Browne; and careful attention should be paid to the peculiarities of his system. It rests upon two conventions.

(1) A single atom is to be represented by a single point.

(2) A single valence bond is to be represented by a single line drawn between two atomic points.

It is true that the atoms in structural formulas are not usually represented by points, but by letters or pairs of letters. These letter symbols, however, serve merely to discriminate between various classes of points. They have no descriptive significance. No one imagines that when the letter C is used as a symbol for carbon, the intention is to indicate that the carbon atom is shaped like a crescent. There is nothing H-like about an atom of hydrogen. As a matter of fact, if carbon were the only quadrivalent element, there would be no necessity of putting the letter C into the formulas at all. The mere fact that four valence lines ended in one point would show that the atom at that point must be carbon. Since more than one kind of univalent atom is known, letter symbols might be avoided by adopting a polychrome notation. Hydrogen atoms could be represented by red points, chlorine atoms by yellow ones, bromine atoms by brown ones, and so forth. Such a notation might be harder to remember than the one in common use and would certainly be more expensive to print. But formally it would be identical with the one now employed. That is to say, it would tell just what the one in use does—no more and no less.

But when atoms are represented by points, a word must be said as to the significance to be attached to valence lines. From the fact that every line consists of an infinite number of points, it should not be inferred that every valence bond consists of an infinite number of atoms. Only the points lying at the ends or the intersections of valence lines count as atoms. The points lying elsewhere on these lines are not to be considered points in this sense at all. In a structural formula a valence line expresses only a relation between two atomic end or intersection points. This valence symbol must be written, and it cannot well be put on paper without making use of other points besides the atomic ones, but structural formulas clearly distinguish between the points which are to be regarded as representations of atoms and those which are not.

With these ideas in mind, certain important questions may be considered. The structural theory as portrayed in the Crum-Browne notation has been a wonderful success in chemistry. Does this success prove that Berzelius was right in his assumption that the differences between isomers are due to differences in the intramolecular geometry of their respective molecules? This is a difficult question to answer because the reply depends on the answer to another question: What did Berzelius mean when he used the word "geometry"? I can lay no claim to an exhaustive acquaintance with the writings of the great Swedish chemist, but from all that I have ever read or heard, geometry to him meant three-dimensional metric Euclidean geometry, the subject taught in the high-school textbooks. I know of no evidence that he ever thought of geometry in any other sense. But if such is the fact, then the answer to the first question is "No." The structural theory tells practically nothing about intramolecular geometry in the sense in which Berzelius used that word. On the contrary, for all that theory tells, the individual molecules in a given sample of pure substance may differ widely in respect to their intramolecular arrangements—using that term in the Berzelius sense.

But if the word "geometry" is used in a far wider sense, as it is employed by modern mathematicians, then the answer to the foregoing question is very different. The structural theory tells a great deal about the intramolecular geometry of the substance in question, only the geometrical system used is not the one which Berzelius had in mind. The forthcoming demonstration therefore falls into two parts. First, to prove that the geometry involved in the structural theory is not the Euclidean system which Berzelius had imagined. Second, to investigate the geometry actually involved in the structural theory and if possible to identify it with some one of the infinite number of geometries contemplated by mathematicians.

Both of these objects may be pursued by considering what mathematicians call "invariants"—a subject to which a few words of explanation are here devoted. If any one wishes to use a particular geometry (meaning, of course, the theorems of that geometry) to elucidate an experimental situation, he must first state which geometry he intends to use. If the system proposed is one of the small number of geometries which have already been extensively used for similar purposes, and to which familiar names have been given, then it may be designated by name. But if the proposed system is some little known and unnamed geometry, it may be somewhat difficult to identify. Of course, a list of its axioms may be given, but to do so may not be the most convenient method of designation. Mathematicians have been very ingenious about devising a scheme which sometimes greatly curtails the process of describing a particular geometry. They have shown how any geometry may be identified by its "invariants."

In every geometrical system, certain diagrams are regarded as equivalent and certain ones as non-equivalent. What are the rules for such equivalence in the familiar Euclidean system? When are two Euclidean diagrams A and B equivalent? In the first place there must be a one-to-one correspondence between the individual points $a_1 \ldots a_n$ in diagram A and the individual points $b_1 \ldots b_n$ in diagram B. But this is not enough. Suppose $a_i a_j$ represents any pair of points in A, and $b_i b_j$ the pair of corresponding points in B. Then the distance between a_i and a_j must be the same as that between b_i and b_j. Or suppose that the Euclidean diagram A be moved—as the mathematicians say, transformed. In its new position it may be considered equivalent to itself in its old position provided that it is not in any way distorted during the transformation, which is the same as saying that after the transformation the distance between any pair of points (a_i, a_j) is the same as it was before the transformation. That is, the particular function of a pair of points called the distance between them is not changed by passing from one diagram to an equivalent diagram—is not changed by any Euclidean transformation. In other words, length or distance is an invariant of Euclid's geometry. If a two-dimensional system of Cartesian coördinates is set up and the two points a_i and a_j labeled by their coördinates x_i, y_i and x_j, y_j, then the function

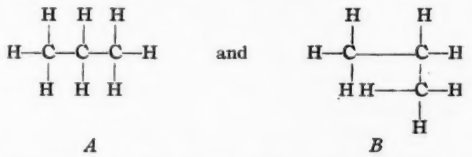
$$(x_i - x_j)^2 + (y_i - y_j)^2$$

must remain invariant if the diagram is to remain unchanged in the Euclidean sense.

In geometries other than Euclid's, length or distance may cease to be an invariant. Take, for example, one particularly simple form of projective geometry which might be called shadow formation by an infinitely distant light source. In this system, every diagram is considered to be equivalent to its shadow. Shadows cast by the sun are a good example of this sort of projection, and everyone knows that the length of his shin is not necessarily the same in his shadow as it is in his leg. Therefore, length is not an invariant of this sort of projective geometry. But it should not be imagined on this account that the geometry in question has no invariants. If, in the shadow of an erect man, the length of his shin is distorted, then the length of his thigh is distorted in just the same proportion. The length of the shin and the length of the thigh may both be changed, but the ratio between them is just the same in the shadow as in the leg. Here the invariant is not length, but the ratio between lengths parallel to a given axis, and this invariance characterizes a particular kind of projective geometry just as the invariance of length characterizes the ordinary Euclidean geometry.

A sufficiently competent mathematician might go on through the various sorts of geometry—Euclidean, projective, affine, contact, Cremona, and so forth, showing how each one of these systems is characterized by its own particular set of invariants. But my knowledge of the subject is too limited to permit such a demonstration. Therefore, only one more illustration will be given. The particular one chosen is selected because it has long been familiar. Suppose the intention is to make a diagram drawn on a plane equivalent to one drawn on the surface of a sphere. This is the map-maker's problem. It can be solved in a variety of ways, but a method frequently adopted is to use Mercator's projection. And the reason why this particular sort of transformation is employed is because of one of its invariants. On a map drawn by Mercator's projection, the angle defined by any three points on the plane is the same as the angle defined by the corresponding three points on the sphere. In other words, under this transformation, or in this particular sort of geometry, the magnitude of angles is an invariant. It is for this reason that maps drawn by Mercator's projection are useful for navigation. Everyone who has ever looked at such a map, however, knows that on it distances, even relative distances, are grossly distorted. In other words, length and ratios of lengths are not invariants of this sort of geometry.

Returning now to structural formulas, consider the diagrams *A* and *B*.



A *B*

They both refer to the same substance, propane. Annually it is explained to sophomores that such differences in formula are without structural chemical significance. But students are not usually warned that the disregard of such differences means the abandonment of Euclidean geometry for the purposes of structural chemistry. The two formulas given are not equivalent as Euclidean diagrams, for it is impossible to pass from one to the other without altering at least some of the lengths which are Euclidean invariants. In a Euclidean structural system, the two diagrams would have to be considered to refer to two distinct compounds. It has been decided not so to consider them. That is a perfectly permissible decision, and to my mind a wise one. But the consequences of the adoption of this convention must be faced. If anyone imagines that a system so designed can tell him anything about the Euclidean geometry of the molecules represented, he is merely deluding himself.

So far, it has been demonstrated that the geometry of the structural theory is non-Euclidean. There remains the more difficult question: What is the particular kind of non-Euclidean geometry involved in structural chemistry? One way to obtain an answer to this question is to imagine a diagram drawn on an elastic sheet, and, further, to imagine that the sheet is composed of a highly idealized form of rubber which can be stretched or compressed indefinitely. Next, assume as the permissible transformations of a geometry any distortion of the rubber sheet which does not result in tearing apart or cementing together the fabric.

Clearly, if the diagram is a circle, it can thus be transformed into an ellipse—which is the same as saying that, in this particular geometry, circles and ellipses are equivalent figures. Moreover, by pulling the sheet in various directions at once, a circle can be transformed into any lumpy potato-shaped figure. By laying the sheet on the surface of a cylinder or a cone, the same circle can be changed into a more complex three-dimensional curve. In fact, by suitable pulls and pushes it can be transformed into any closed analytical curve which nowhere intersects itself. All of these figures are equivalent in the geometrical system adopted. Clearly, neither lengths nor the ratios of lengths, neither angles nor the ratios of angles are invariants of such a system.

A reader might at this point be inclined to ask, "What can be done with a geometry so fluid and amorphous as the one described? What is there left to be invariant

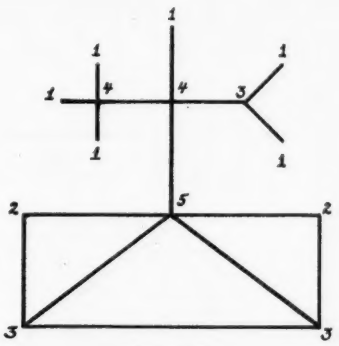


FIGURE 1

under such a system?" It is, however, easy to show that there are still some very important invariants. In the first place, although, under this system, a circle can be transformed into many other sorts of closed figure, it cannot be transformed into a straight line, a parabola, or any other open curve. Consequently, it might be said that the "closedness" of curves is here an invariant. Furthermore, if the circle were divided into segments by placing dots on it, no distortion of the rubber sheet would ever alter the number of dots or of segments. No two dots would ever coalesce; no single dot would ever split up into more than one. Again, if some of the dots were colored blue and others red, no distortion of the sheet would ever turn a blue dot into a red one or *vice versa*. That is to say, under this system there remain as invariants the number of segments into which the circle is divided and any particular classification of the boundary dots which may be adopted.

Consider next a more complicated figure such as the one shown in Figure 1. Here only the ends of lines and their intersections are regarded as real points in the diagram. A line between two such points merely indicates that the two points in question are to be considered adjacent to one another. Note that with each of these end or intersection points there is associated a number. This number is the number of segments which end in the point under consideration. Mathematicians frequently speak of a point at the end of only one segment as a single point, one at the end of two segments as a double point, and in general, one at the end of n segments as a point of multiplicity n. But it is convenient here to borrow a little terminology from organic chemistry and to speak of the valence of these points. An n-valent point is one which lies at the end of n segments.

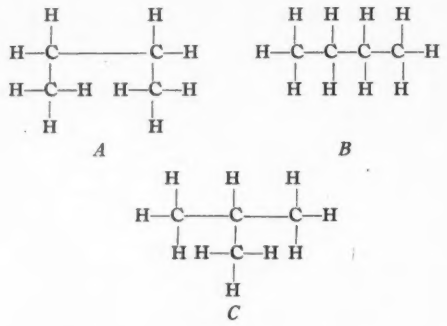
It should be self-evident that no distortion of the rubber sheet will ever transform an n-valent point into one of any other valence. But there are other properties of the diagram which are also invariant. For example, there is in it just one trivalent point adjacent to a quadrivalent one. No matter how the sheet is stretched or twisted this property remains unchanged—and the same is true of all the other adjacency relations originally fixed by the figure. Hence in this fluid, amorphous geometry, the valence of points and the adjacency relations between them are characteristic invariants.

This "rubber sheet" geometry has long since attracted the attention of mathematicians and has received a special name. It is called "analysis situs" or "topology," and much has been written on the subject. This large body of knowledge may be divided pretty sharply into two parts, the first dealing with finite collections of points, and the second with infinite collections. Only the former portion is of importance here, for in order to apply theorems dealing with infinite collections of points to problems of structural chemistry, it would first be necessary to find molecules containing infinite numbers of atoms. I regard the notion of such molecules as pretty close to an absurdity.

At this point it is desirable to give an example in order to show what a proposition in this topological system may look like. Clearly, it cannot deal with lengths or angles, for topology pays no attention to these aspects of diagrams. Nevertheless, there are plenty of geometrical properties still left to talk about. In fact, the topological theorem next quoted is a famous one first proved by Euler. "In any solid figure bounded by faces, edges, and apices, the number of faces plus the number of apices is equal to the number of edges plus two." This statement may be easily verified by application to any solid object. The proposition is quoted in order to show that, fluid and amorphous as topology may seem to anyone accustomed to Euclidean rigidity, its theorems are by no means lacking in either scope or vigor.

Long before this, it has doubtless been apparent what application is here to be made of topology. In structural formulas neither the lengths of lines nor the magnitudes of angles are considered. On the other hand, all the various forms in which a single structural formula may be written must preserve as invariants the valence numbers of the different sorts of atoms and the

adjacency relations between the members of the various atomic pairs. Consider the diagrams *A*, *B*, and *C*.



A and *B* refer to the same compound (normal butane) and as topological diagrams they are identical. *C* refers to a different compound (isobutane); and as a topological diagram *C* differs from *A* and *B*, because it contains one quadrivalent point adjacent to three other quadrivalent points, whereas no such quadrivalent point occurs in *A* or *B*.

Of course, this example, or, indeed, any finite number of examples does not constitute a geometrical proof. But a strict formal proof is scarcely required at this point. In structural chemistry, no matter how the valence bonds are stretched, no matter how the angles are varied, if any two formulas refer to the same compound or to structurally identical compounds, they are identical as topological diagrams. If they refer to structurally different compounds they are not identical as topological diagrams. This assertion (which anyone can verify to his own satisfaction) is the basis for the statement that the geometry involved in structural chemistry is that particular geometry known as "analysis situs" or "topology."

Thus structural theory throws practically no light on the Euclidean geometry of molecules, but completely determines their topology.* And so there arises a serious question in terminology. How is the word "structure" ordinarily used by architects, engineers, and the like? If an architect saw the two ground plans here given (Figure 2), he would certainly not regard the two houses as structurally identical. Yet, as topological diagrams, there is no difference between these two drawings. Consequently one is faced with a dilemma. If the word "structure" is used in its ordinary sense, then it must be admitted that Kekulé's theory is not a structural theory at all but a topological theory. If the word "structural" is applied to this theory, then it must not be forgotten that this term is here used in a very special sense, sharply at variance with the sense in which it is usually employed. I am not going to try to offer advice on this point. Everyone must follow his own judgment. But it is greatly to be regretted that so unfortunate a situation should ever have arisen. To give a common word a peculiar meaning is to take a risk. Anyone who does so in the present instance is likely to forget that he is using the word "structural" in the special sense indicated, and then he is in grave danger of reading into structural diagrams Euclidean meanings which are never justified and frequently false.

However, it may be of interest to state that there is one body of scientists who use the word structure in exactly the sense in which it is correctly employed by chemists. These are the mathematical logicians, who are interested in relations. When they have a collection of objects some of which are, and some of which are not, connected by a given dyadic relation, they plot the relation in a diagram just as chemists plot the valence relation in a chemical structural formula. After they have finished, they call the diagram the structure of the relation within the field (or collection) under consideration. The only important differences between

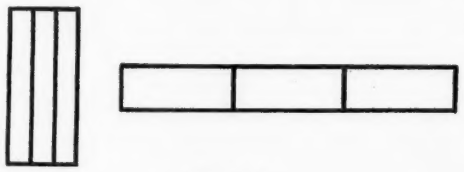


FIGURE 2

their problem and the chemical one are, first, that they are not always thinking of symmetric relations and so they sometimes have to use arrows where chemists use only lines, and second, that they do not usually demand that the whole field be embodied in one coherent diagram. This last difference means that, if they were chemists, they would like to think of several sorts of molecules at once instead of considering them one at a time as actual chemists usually do. To some people it may be a comfort to know that there is such a fine precedent for the chemical use of the word structure. But I do not feel that chemistry has to serve as a tail for anyone else's kite. Chemists have a right to use the word structure in any sense they please, provided that they clearly define its meaning and do not then go off and forget the definition.

The argument so far has justified the statement that a molecule is a collection of a finite number of atoms associated with a topological diagram.† What then can be inferred about the nature of molecules and atoms? One thing and only one thing is sure. If there exist finite collections of objects with which no topological diagram can be rationally associated, then certainly an atom is not that kind of an object and a molecule is not that kind of a collection. But are there any such objects and any such collections? That

* It is possible to imagine compounds for which this statement would not hold. But as no such compound has ever been prepared, the assertion is allowed, for the sake of brevity, to stand unqualified.

† As usual in structural theory, the word "molecule" is here only an abbreviation of the phrase "neutral molecule or dissociated ion."

question I cannot answer. I can, however, give a sufficient condition which, if fulfilled by a finite collection of objects, allows a topological diagram to be rationally associated with that collection. This condition is as follows: If any finite collection constitutes a coherent subfield under a symmetrical dyadic relation which produces a dichotomy of its proper unordered pairs, then the collection can be rationally associated with a topological diagram. There is no occasion here to explain fully this precise though somewhat pedantic statement. It is sufficient to say that the definition includes a large variety of collections which chemists

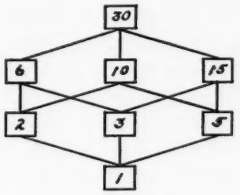


FIGURE 3

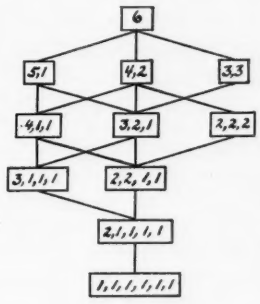


FIGURE 4

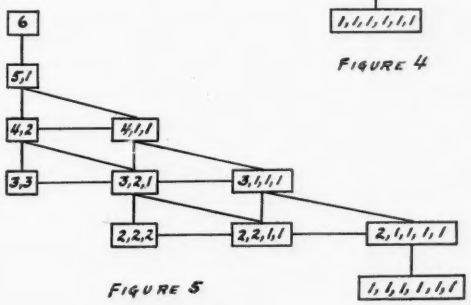


FIGURE 5

do not usually associate with topological diagrams. For instance, various topological diagrams can be associated with any collection of positive whole numbers, or with the partitions of any one positive whole number. The figures given (3, 4, and 5) show one of the topological diagrams which can be associated with the factors of the number 30, as well as two distinct topological diagrams which can be associated with the partitions of six. A chemist might call any one of these diagrams a structural formula of the collection in question.

These examples are instructive, not because they show what can be inferred from the structural theory, but because they call attention sharply to certain inferences from this theory which, though frequently made, are entirely illegitimate. For instance, from the fact that every molecule is associated with a topological diagram, is it correct to infer that molecules and the atoms which compose them are objects which can be localized in time or space? If this inference is sound, then it follows that the factors of 30 can also be so localized because it is just as easy and just as correct to associate a topological diagram with the factors of 30 as it is to associate such a diagram with the atoms of the ethane molecule. But obviously there is no sense in such questions as: Where is 15 now? When was 6 up on the roof? And if the topological diagram of 30 does not make such questions sensible, then neither does the topological diagram of ethane furnish any assurance that the atoms of that substance can be localized in time and space. Certainly I do not maintain that atoms and molecules are not so localized. For aught I know they may well be. All that is here emphasized is that structural chemistry furnishes no evidence either pro or con on which an opinion about this question can reasonably be based. As previously stated, the subject under discussion is not what is known about atoms and molecules, but what the structural theory tells about them. Well, it tells that molecules have topological diagrams, and that is all it does tell.

It may be thought by some that this reticence on the part of the structural theory constitutes a weakness in that theory. But I do not hold this view. On the contrary, it is because the structural theory preserves a sphinx-like silence on questions of the sort just mentioned that it has proved so useful, has lasted so many years, and still bids fair to have a long and honorable career before it. Take the parallel instance of thermodynamics. The theorems of that science deal with equilibria, but nothing in them refers to any possible mechanism by which these equilibria are attained. Few scientists have reason to question the kinetic theory. But if that theory were proved to be arrant nonsense, the discovery would not trouble a thermodynamicist. He would merely say, "I have nothing to worry about. I never vouched for the kinetic theory. It may be sound, or it may be unsound. Whether it is one or the other affects neither the validity of my arguments nor the correctness of my conclusions. Thermodynamics is independent of all such theories."

Suppose it were to be proved tomorrow that atoms are pure abstractions like numbers or functions. Such an event is in my opinion most unlikely, but if it did occur, a very large portion of chemical theory would be swept at once into the discard. If such were the nature of atoms, and if molecules are collections of atoms, then neither of these entities could possibly have many of the properties which have customarily been attributed to them. But the structural theory would not be at all affected by such a discovery. The structural chemist might well say, "What difference does it make to me whether or not atoms or molecules are pure abstractions—like numbers? Collections of such abstractions can have topological diagrams just as well as other sorts of collections. All that I ever said about molecules is that they have topological diagrams. That is just as true now as it ever was. For my purposes this catastrophic discovery is entirely irrelevant."

It is curious and sometimes even discouraging to see how some organic chemists, placed by good fortune in an almost impregnable position, seem bent on weakening

the stronghold of their science. Instead of standing guard jealously over their beautiful and powerful theory, instead of doing their best to keep it from being weakened, they strive eagerly to undermine its deep foundations, and to deface its mighty walls. If they succeed in their attempts, it will eventually tumble into an unsightly heap, a by-word, and a reproach for the physicist and the mathematician.

A CONVENIENT STEAM DRYING OVEN

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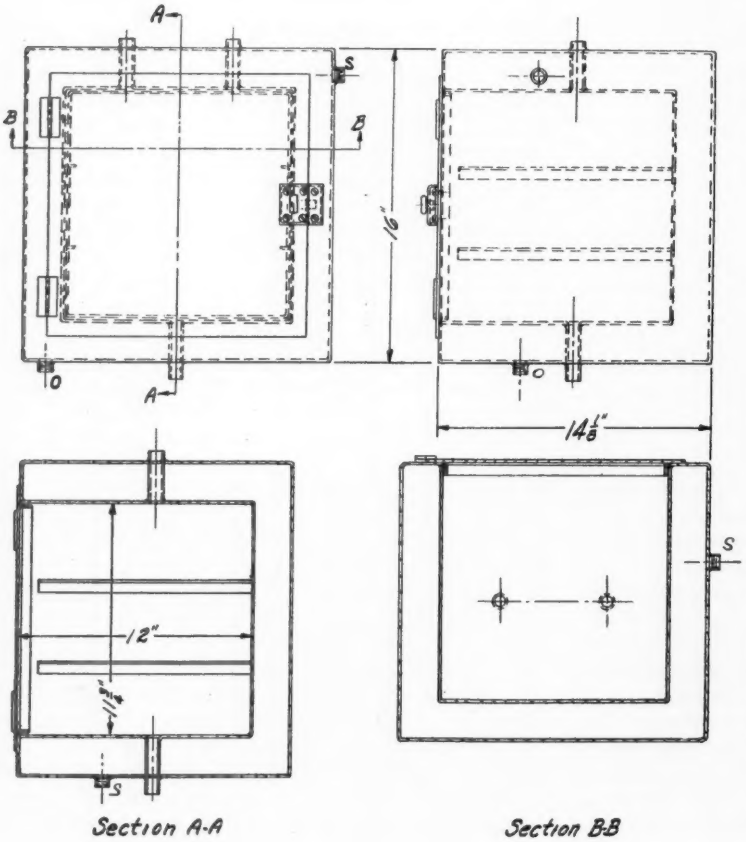
THIS article is a description of a double-walled steam oven that has proved to be very convenient for laboratory work. It is simple in construction, economical in operation, and maintains a moderately uniform temperature.

The oven is made of sheet-steel of 10-gage thickness, welded together with the oxyacetylene torch. It is designed to be used on a low-pressure steam line where a uniform pressure is maintained by the automatic stokers that fire the boilers. If the available steam pressure is too high, it may be reduced by means of a suitable reducing valve. With a pressure of five pounds the temperature of the oven is maintained between 100° and 105°C., which is suitable for drying operations. The top of the oven makes a very convenient low-temperature hot-plate for evaporations to dryness in quantitative analysis.



The upper left-hand drawing shows the front of the oven with the door hinges and latch. The steam enters at *S* and the condensate drains off at *O*, which is connected through a trap to the return lines. At the bottom is an opening for admitting air, and at the top two openings, one for a thermometer and the other for ventilation. With the openings at the top and bottom a current of air is drawn through the oven, increasing drying efficiency. The upper right-hand drawing is a side view, showing the arrangement of the shelves which rest on angle irons welded on the inside of the oven. The lower drawings represent vertical and horizontal sections inside the oven.

The COURSE *in* PHYSICAL CHEMISTRY*

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OF THE various courses in chemistry which the student of chemical engineering must take, the course in physical chemistry is probably the most important. Certainly a thorough grounding in the principles of physical chemistry can be of great help to the student before the final course in unit operations. It should be taken during the third year and because of the wide choice of subject material, departments of chemistry and those responsible for the administration of physical chemistry courses should realize the special nature of the requirements they have to meet in dealing with chemical engineering students. It may be said with a certain amount of justification, I think, that certain branches of the subject have an importance for the chemical student and yet are of doubtful value to the chemical engineer. Let me quote from a recent up-to-date text written for undergraduate students some of the topics which are given detailed consideration: an advanced treatment of the kinetic theory; rigorous derivations of equations expressing the vibrational heat capacity of di-atomic and poly-atomic molecules; the Debye and Hückel theory for dilute and concentrated solutions; rates of chemical reaction from the standpoint of statistical mechanics; the behavior of atoms and electrons from quantum considerations; the translational energy states of a particle; and so on. Needless to say, these topics are most excellently and lucidly treated and while they are of outstanding importance to the chemist, they are not likely to be of great value as a preparation for the unit operations of chemical engineering. The text I have mentioned is perhaps, despite the name "elementary," more advanced than is usual for undergraduate work, but we might as well recognize that as developments in atomic theory continue to occupy the attention of the chemist the separate training of the chemical engineer becomes necessary. In some schools where both groups take the same course it has been found necessary for the chemical engineering department to bridge the gap between chemical principles and unit operations. These courses are given a variety of names: Industrial Chemical Calculations, Chemical Engineering "2" and so on. An excellent text for this type of course is finding widespread use and has already gone into two editions. It comes nearer being the type of text chemical engineering teachers want than most of the books written for the needs of the chemical student.

The average textbook in physical chemistry considers in some detail the ideal gas laws and devotes scant consideration to actual gases which are after all important to the chemical engineer. Furthermore, the type of problem usually considered is simple and misleading. The simple gas laws can be used to develop reasonably complex problems in industrial stoichiometry, but seldom do we find them included. The literature of chemistry and physics has an abundance of P-V-T data for actual gases. From these data compressibility factors may be computed. The student should be required to construct a few of these charts employing compressibility-pressure and compressibility-volume for different temperatures and, say, three different gases. They can be used in a wide variety of problems in which actual gases are dealt with. Time devoted to this work is worth while and may give a better insight into the behavior of gases than a lecture or two dealing with the van der Waal equation. Then again in computing isothermal work many students are able to integrate the PdV term only if the relationship between P and V is given. They seldom stop to think that graphical integration may be the only method available. The P-V-T values are to be again useful when the fugacity is being considered.

Thermodynamic treatment of subject matter has now been almost universally adopted and it is well, I think, to develop the first and second laws of thermodynamics before the liquid state is studied.

In citing applications to the first law such topics as enthalpy, heat capacity and thermochemical reactions should be illustrated by means of heat balances on furnaces, gas producers and industrial chemical equipment. In these problems the student should be encouraged to seek his own data from the literature. He may be unable to find equations expressing a relationship between C_p and T. If mean specific heats are available graphical differentiation will have to be resorted to or if only instantaneous C_p values are to be found he will have to graphically integrate. Usually the data will come from so many different sources that it will require considerable working up before it can be turned to the problem at hand. Everything should be done to disabuse the student of the thought that his problems will leap neatly into his mind complete with all the data to be solved. The stereotyped textbook

* Contribution to the Symposium on Chemical Engineering Education, conducted by the Division of Chemical Education at the ninety-fourth meeting of the A. C. S., Rochester, N. Y., September 7, 1937.

problems should be gotten away from as early as possible.

The important concept of entropy in many elementary texts has been omitted despite the inclusion of the Lewis and Randall free energy. In their desire to sidestep entropy authors have resorted to cycles. The derivation of the Clapeyron equation is a case in point. In this cycle quantities of the second order are dropped out so that finally everything comes out all right. This could be avoided by using the generalized equation for the free energy of which the entropy change is an important part. Entropy is, as we know, the quantity factor of heat energy and for this reason alone should be included. Moreover no consideration of the second law is complete without it. It seems to me that we are just as much interested in the irreducible amount of energy which is degraded as we are in the maximum amount of work recoverable, and yet, it is not unusual to find the latter considered, and not the former. The widespread use of temperature-entropy and total heat-entropy diagrams for such substances as ammonia, carbon dioxide, nitrogen, hydrogen, and a few hydrocarbons in problems dealing with liquefaction and compression should be kept in mind. Without encroaching on the thermodynamics course, we have found it good practice to have our students construct such diagrams which they can use later in that course. Temperature-entropy diagrams will also be used in calculations involving chemical equilibrium.

The greater part of the thermodynamic principles will be thus developed early in the course before the liquid state. The student will then be in a position to apply his free energy functions to liquid-vapor systems and as each new system is encountered he will learn more about what it really is through its repeated application.

There will be many, no doubt, who object to this method by which the student early in his course is already struggling with such variables as P, V, T, U, H, q, S, A, and F, but we should not lose sight of the fact that he knows how each can be physically measured. He has made graphical representation of certain pairs of these variables and is in a strong position to apply them to more complex systems.

He is troubled, of course, because he can no longer have a physical picture in his mind's eye of an equation such as $(\partial S/\partial V)_T = (\partial P/\partial T)_V$ although he can derive it readily. This need not cause undue concern on the part of the teacher, who might confess to something of the same difficulty, but everything shou'd be done to show the type of physical measurements necessary so that the equation can be applied to some useful purpose. The philosophy underlying the first and second laws deserves some consideration as the course develops. The student usually becomes fascinated with this phase of the work. Excellent outside reading may be suggested.

We have three methods by which the subject may be presented: (1) the mathematical; (2) the experimental or applied; and (3) the philosophical. As you know, it is possible to go on and on developing precise mathematical equations expressing relationships between the variables, and facility of this sort is readily acquired. It is the compromises which have to be made in translating these equations to actual systems which make the second method of treatment so difficult. It represents, however, the greatest value to the engineer.

In dealing with the liquid state certain topics are worthy of treatment. Surface tension, viscosity, vapor pressure, and latent heat should all be discussed with some detail. These topics receive further emphasis in laboratory work. It might be mentioned in passing that Poiseuille's equation of flow through capillary tubes, although found in most texts, is rarely derived. The effect of total pressure on the vapor pressure; the vapor pressure of small droplets; Duhring's rule; the law of corresponding states; polar and non-polar liquids are all worthy of study.

The extent to which the solid state is treated will depend on whether or not physical metallurgy is given in the curriculum. Usually both courses run at the same time. If no course in physical metallurgy is given, the teacher will do well to include some work on X-ray diffraction as a means of determining crystal structure.

It may be said that in the field of solutions the teacher can use his greatest influence in steering the course away from a detailed analysis of dilute solutions. If texts are to be written to suit the needs of the chemical engineer they will suffer greatest modification in this field. Many of the dilute solution problems belong to the freshman year of the course. We are interested in studying, for instance, Raoult's law, in knowing where it applies, and in knowing the type of deviation suffered by various liquid pairs. Positive and negative deviations may be readily studied by considering partial volumes. This suggestion might be followed through and correlated with the laboratory work of the class, and much valuable information will thus be collected. The Duhem-Margules relation should also be brought into use. Construction of temperature-composition and pressure-composition, as well as x-y diagrams for six pairs of liquids will do much to help the student later on in distillation. The Rayleigh equation should be included and studied quantitatively. The idea of relative volatility is one that apparently only finds its way into chemical engineering textbooks. It is really quite remarkable that so little work has been done toward considering the separation of three-component liquid systems in our physical chemistry courses.

A thorough study of solutions is helpful also to a better understanding of the unit operation of evaporation. It can be made helpful if the treatment is strictly quantitative. The student should be well grounded in the various methods by which the composition of a solution may be expressed. From the different kinds of solubility diagrams he should be able to find the weight of crystals obtained when a given weight of

solution is cooled through a given temperature range, starting with simple solubility diagrams in which no compounds are formed between solvent and solute to complex cases where the solids form solvates with congruent points and finally to mixtures which have to be separated by fractional crystallization. The student learns much that is useful by solving numerous problems centered around these diagrams.

The use of the Merkel chart in evaporation problems affords an interesting application of partial heats of solution. In essence the method has already been studied when the partial volume was discussed. The added complication of standard states which are arbitrary may be hard to put over, but it is a concept common to free energy, entropy, enthalpy, and internal energy. Students who find the idea difficult are advised to study the steam tables and to try the effect of shifting the reference temperature from 32°F. to some other temperature.

The underlying idea in the physical chemistry course is really to consider those parts of the subject which have a direct bearing on the unit operations of chemical engineering; to make available the vast amount of data which he can use in his work if he masters the principles of his subject; to shun those portions of the subject which for the present, at least, seem to have no relationship to engineering practice; to familiarize the student with engineering units; to pin down every principle and equation to concrete examples, and make the course rigorously quantitative.

Another important viewpoint which needs stressing is that of equilibrium. In many industrial reactions and processes, equilibrium is not reached because of certain defects inherent in the system. We try to bring this out in a careful selection of rate problems. After disposing of the usual list of first-, second-, and third-order reactions we consider problems which have to do with rate of solution of gases and solids in liquids, rate of leaching, rate of adsorption, and rate of distribution.

No attempt has been made to give a complete account of all the topics covered in the course. A minimum time of one year is suggested of not less than three lectures a week, given during the third year. It is important that the methods of teaching should cause the student to think, regardless of course content. It must be taught so that mere memorization of a series of formulas will not enable the student to pass the course. We have found the open book examination a good corrective to blind memorization of facts and formulas. The principles which have to be mastered are relatively few, but they must be clearly understood before they can be applied to the solution of difficult problems.

INSTRUCTIONAL RELATIONSHIPS *between* CHEMISTRY *and* CHEMICAL ENGINEERING*

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THE chemist and the chemical engineer have much in common. They have a common origin and their methods of investigation and trends of thought are analogous.

The past decade has, more than any other, indicated diversification in their training and in their literature. The belief is still prevalent, however, that a sound fundamental training in the principles and heories of chemistry is essential to the subsequent satisfactory training of the chemical engineer.

This has received its due emphasis in the suggested time allotment, in the curriculum promulgated by the Committee on Chemical Engineering Education of the American Institute of Chemical Engineers, of twenty-five to thirty per cent. of the students' time to chemical subjects and twenty to fifteen per cent. to chemical engineering subjects.

It might be wise at this time to "qualify the witness" —more than thirty-five years a member of the American Chemical Society, a teacher of chemistry for ten years or more and for twenty-five years the director of the chemical engineering option of a school recognized by the Committee on Chemical Engineering Education, to be giving a satisfactory course in Chemical Engineering.

Assume that such a witness is testifying and voicing his conceptions as to the contributions which the proper teaching of chemistry can make in the training

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of the chemical engineer. The foundation is laid with that subject matter customarily comprised in the term general chemistry. The chemical engineer is going to be interested in the *physical* as well as the *chemical* characteristics of the elements and their compounds, so the inclusion of some material of this type will be of distinct value. It is also believed that the student's interest in the course can be stimulated by some citations as to the influence of certain characteristics on industrial uses of the materials and on the processes involved in securing the elements and their compounds.

An excellent illustration of the kind of instruction desired is exemplified in a recently built sulfuric acid plant. The student is probably informed that *dry* sulfur dioxide has no corrosive action on the customary iron alloys, but this can be driven home by describing the sulfuric acid system where molten sulfur is atomized with *dry* air and the combustion gases, like ordinary combustion gases, give up their heat to generate steam in steam boilers, and that more than enough power is obtained from these boilers to operate the entire plant.

Some other excellent examples are to be found in the electric or in the blast-furnace production of phosphorus and its compounds. The sulfur and the phosphorus compounds are supposed to be closely related chemically; chemically, therefore, there should be no objections to oxidizing the phosphorus in dry air and utilizing the heat thus produced. The chemical engineer, to date, has not attempted this, being deterred by the constructional and operating difficulties where the oxidation product is a solid rather than a vapor.

Instruction in analytical chemistry affords opportunities of other kinds. One of the major laboratory interests of the student consists in the formation of precipitates and the separation of them, by filtration, from the liquids in which they have been formed. Quite analogous is the *industrial* practice of filtration with the same importance to be ascribed to correct technic.

Some precipitates are produced in the cold and filtered cold, others are produced in the cold but heated to boiling and digested for a time prior to filtration; there are a dozen and one diversifications of the cited procedures. Back of all these varieties of procedure are certain fundamentals. Bring them forth for the student's consideration. Tell him something about hard crystals and soft crystals, about conditions favoring increase in crystal size, and a few words in regard to influence of pH on crystal formation will not be out of place.

It might also be well to tell him that precipitates are either crystalloid or colloid, that colloids do not filter satisfactorily, but that certain changes in solution may cause colloids to floc, which permits their filtration. Call attention to the decrease in viscosity of water between 20° and 100° with specific figures cited.

The case for industry is even more marked in favor of the heated solution; for example, a petroleum distillate may have a viscosity of 2.99 at 15.6° and 0.049 at 100°. Advantage is taken of this in industrial filtration.

The proper selection of filter paper for the type of precipitate being separated is important, perhaps not on account of the separation, but certainly on account of the time factor. The chemist using only one grade of filter paper for all his filtrations is just as unintelligent as a chemical engineer who might insist on one grade of canvas for all industrial filtrations; therefore, call attention to the existence of various grades of filter paper, indicate the saving in time made possible by the selection of the proper one; then, for the benefit of the chemical engineer, point out the industrial significance of this.

The customary way to use a filter paper is to fold it in a certain way and place it in a funnel. This, too, can be taught in a way to be of particular benefit to the chemical engineer. The rate of filtration depends to a considerable extent on (*a*) pressure differential, (*b*) free area on the filtrate side, (*c*) particle size of precipitate, and (*d*) viscosity of the filtrate.

The free area on the filtrate side refers to that portion of the filter paper not in contact with the glass of the funnel. Filtration occurs chiefly, if not entirely, within this area. Then consider what happens when a filter paper is folded in quarters and placed in a sixty-degree funnel. The Corning Glass Company has begun making Pyrex funnels with a few channels; is this the correct procedure? Ask your students, but be sure you have the correct answer for yourself first. All this may well serve as the young chemical engineer's introduction to the unit operation of filtration.

The teaching of organic chemistry has little bearing on later instruction in chemical engineering unless there has been some study of the unit processes included in our chemical engineering curricula. Many of us are coming to the conclusion that this is desirable.

The organic chemistry should then contribute a knowledge of organic chemical reactions, characteristics, and properties. The laboratory technic acquired had best be forgotten when working with the unit processes; all it can or should have contributed is an experimental knowledge of organic chemical reactions and something of the conditions under which they occur.

What may physical chemistry contribute to the chemical engineer's basic preparation? Considered solely as a *course* in a curriculum, much or little depends upon its presentation by the individual instructor.

The major portion of our chemical engineering is cross-hatched and paralleled by the facts and fancies of physical chemistry; however, this has been so completely ignored by the authors of most of our texts on physical chemistry that a student pursuing them would complete the subject without knowing that any of the principles and theories presented had any useful application.

Few students have much interest in abstract matters. Therefore, it is believed that the teacher of physical chemistry overlooks an opportunity when attempting to present its topics without calling attention to their useful applications. These applications of physical

chemistry occur essentially in the *practice* of chemical engineering, not in its formal study. In essence a student can complete the undergraduate study of chemical engineering as embodied in our customary curricula without having studied what is termed physical chemistry. A knowledge as elementary as that acquired in general chemistry will suffice. Such topics are involved as the gas laws, Avogadro's hypothesis, Raoult's and Henry's laws, and not much else.

An examination of what is involved in practicing chemical engineering yields a different answer.

It would be impossible for the chemical engineer to design equipment, to plan and to operate chemical processes without having extended this elementary knowledge to include: rates of reaction, heats of formation, free energy components, and so forth. Referring again to the production of sulfuric acid; the designing engineer must know the rate of oxidation, in contact with a certain catalyst, and the equilibrium constants, through a certain temperature range, before the equipment can be satisfactorily designed.

The design and operation of a metallurgical furnace is likely to involve the heats of formation and the fusion points of some complex silicates. The satisfactory production of a soap involves a knowledge of the solubilities of soap in sodium hydroxide solution, of water in soap, of soap in water, and of soap in sodium chloride solution. This knowledge was once only empirical; now it is theoretical as well, and it is probably conceded that better, more uniform soap has resulted.

Many other citations might be given, all of them, however, being connected with the practice of chemical engineering rather than with the formal training preceding its practice. The subject matter presented naturally leads to the question, "Can the teacher of chemistry present these subjects in the manner indicated unless at least an elementary knowledge of chemical engineering is possessed?" My own answer is, "The more the teacher of chemistry knows about chemical engineering, the better he will be as a teacher of chemistry to chemical engineers." This should not lead to any particular difficulty, as for several decades many chemists have imagined themselves to be chemical engineers.

There remains another contribution from the chemistry courses, somewhat indefinite, yet very real. This has to do with the evaluation of experimental data and trends of thought arising in any investigation. Here the chemist and chemical engineer meet on common ground so that technic and habits of thought acquired in chemistry courses can and should carry over into the chemical engineering courses.

Importance is attached to the sequence of topics in the curricula. A resurvey of the material heretofore presented indicates the following: general, analytical, and organic chemistry to be presented prior to the subject matter of chemical engineering; physical chemistry to be presented prior to or concurrent with this subject matter.

Are there any other chemical subjects of prime importance to the undergraduate chemical engineer? The answer is *No;* but for the practitioner in chemical engineering a broader and deeper knowledge of chemistry will be very helpful, keeping in mind the fact that the most extensive training in chemistry will never produce a chemical engineer.

INTEGRATION *of* FUNDAMENTALS *in the* LAST YEAR *of the* UNDERGRADUATE CHEMICAL ENGINEERING COURSE*

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IT IS my intention in this paper to outline very briefly a general philosophy of the undergraduate course in chemical engineering which has been slowly evolving as a result of about fifteen years of teaching experience and to show how the main points of this philosophy may be put into practice with particular reference to the curriculum of the senior year. There is nothing radically new about my concept, but it seems to me that it does lead to a combination of courses in the last year which is quite different from that found in the usual chemical engineering curriculum.

I shall avoid the issue as to the most desirable length

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of time for an undergraduate course. What I propose can undoubtedly be done more satisfactorily in five years than four years. I am not even sure that it is possible to do it in four years, but I shall confine my specific proposals to the last year and it is immaterial to the argument whether it be the fourth or fifth year.

I shall limit my discussion to technical courses. This does not mean that cultural or humanistic studies are to be omitted from the curriculum. I firmly believe that there should be a continuous thread of cultural development throughout the undergraduate course, but that is another story which is beyond the scope of the present discussion.

Briefly stated, my thesis is that the first three (or four) years of the course should be devoted to learning the fundamental facts and principles of certain basic sciences, without much regard to their application to actual engineering situations and the last year should be of a wholly different character in that the emphasis shifts entirely from primarily storing knowledge to applying the accumulated knowledge to solve problems of the type that one is likely to meet in the practice of engineering. This is scarcely a novel idea, but if it is followed to a logical conclusion, it seems to me that it ought to lead to a greater differentiation between the senior year and the preceding years than that which prevails at the present time in the average engineering course.

OBJECTIVES

Before attempting to translate my ideas into the concrete form of courses and a curriculum it may be well to review some of the most important general objectives of an engineering course. These are fairly obvious truisms, but I find it highly desirable to review them frequently so that they are constantly available as guides to direct one's thinking about curricula.

It is commonly said that we should endeavor to train men to *become* engineers after they graduate. This is a very simple but highly important concept. To me it means the elimination from the curriculum of all specialized courses that deal wholly with the details of a particular industry or of any narrow field. We should avoid all pleas to give this or that special course because the graduate ought to know something about the subject when he gets out into industry. It is impossible to build a curriculum on such a basis. We must select for the three (or four) years of essentially pre-engineering training about which I have spoken, only those subjects which have broad application to all of chemical industry and to confine ourselves to facts and principles of fundamental significance. Side excursions into the details of some special field are only justified as a means of illustrating some principle which is applicable in other fields as well. Three years is all too short a time in which to make even a good beginning toward the real understanding of fundamentals, and, if we divert some of this time to other uses, it is clear that we must sacrifice something that is of greater importance to our stated objective.

It is also generally agreed that we are trying to train men who can do constructive thinking rather than be routine technicians. The latter can perform very satisfactorily under situations which duplicate or are similar to those for which they have received specific training, but they fail when confronted with new situations that call for initiative and originality. A certain number of such men are highly useful in industry, but the universities should at least strive to develop men of a higher type—men who can analyze a new situation in terms of fundamental principles and then formulate a plan for action.

There has been much argument both pro and con on the subject of teaching students to think for themselves. I have no panacea to offer. I merely suggest that we devise the curriculum so that those men who have latent powers in this direction can find an opportunity to develop them by active exercise. There is too great a tendency to stifle any urge of this character by imposing such a requirement of things to be learned that there is no time for anything else.

Obviously, in order to exercise the thinking power, one must have something to think about. Many facts must be stored in the mind ready for instant marshalling. Many technics of a routine nature must also be acquired. In other words, the developing engineer must be equipped with many tools before he can expect to even make a start on the attack of engineering problems. But let us try to select a minimum number of the most important facts and principles to be learned and then allow some time in the curriculum for the student to acquire practice in their application under conditions that call for as much mental effort as possible on his part.

It is well recognized that the problems which the young engineer is likely to meet in industry will seldom be just like any of those solved in the textbooks or handbooks. Furthermore, the field of chemical engineering is all the time becoming broader and more complex, and the natural tendency of those in industry is to expect the young graduate to know more and more things. The teacher, too, feels that he must cover so much ground in order to give the young engineer an adequate preparation to meet future problems, and consequently he tends to add more and more material to the curriculum. It is plainly futile to attempt to meet the situation in this way. What we really need is less emphasis on subject matter and more emphasis on showing the student how to generalize from a minimum of facts and how to utilize material which he can refer to when occasion demands.

Summarizing briefly, the two main objectives of the undergraduate chemical engineering course are:

(1) To equip the student with a selected number of facts, principles and technics from the basic sciences so that he has a kit of tools with which to start to go to work on engineering problems.

(2) To give him practice in marshaling his knowledge and bringing hitherto unrelated parts of it to a common focus for the solution of engineering problems. It is

this bringing together of facts and principles from a variety of fields to aid in the solution of a comprehensive problem that is the process of "integration" to which I referred in the title of this paper.

I imagine that most teachers of chemical engineering would not disagree with me to any great extent on the general objectives which I have outlined. There is, however, considerable disagreement on how these objectives are to be realized. A certain amount of disagreement is natural and desirable. I should not wish to see all chemical engineering curricula cast from the same mold. I do believe, however, that many curricula in operation at the present time are in serious need of revision to bring them in line with these objectives.

GENERAL OUTLINE OF PROPOSED CURRICULUM

To carry out the foregoing objectives I propose to have three (or, if necessary, four) years devoted to the acquisition of the fundamentals of the basic sciences, followed by a final year which is given over entirely to the solution of comprehensive problems of an engineering character. The basic disciplines in which it is desirable that some familiarity with the fundamentals be acquired might be classified as follows:

(1) Basic sciences: The three fundamental sciences of chemistry, physics, and mathematics.

(2) Social sciences: Elements of economics and some applied economics.

(3) Engineering sciences: Engineering drawing, mechanics, materials of construction, thermodynamics, elements of electrical engineering, and unit operations of chemical engineering.

In chemistry I would have only the basic courses in the four well-recognized divisions, namely, general and inorganic, analytical, physical and organic. Note that I would omit all such courses as industrial chemistry, chemistry of fuels, water analysis, electrochemistry, and many others which now occur in some chemical engineering curricula. I do this on the ground that these courses are largely descriptive and informational in character, and the time can be utilized to better advantage on more fundamental things.

There would be the usual basic course in physics. Mathematics should be carried through differential and integral calculus with an introduction to elementary differential equations.

I confess that I am not clear in my own mind how far to go in the social sciences. I think most would agree that there should be a course in general economic theory. I believe that it would be desirable to follow this with a course in what, for want of a better name, I have called applied economics. It would deal with such things as labor problems and other human relations in industry, with elements of cost accounting, problems of buying and marketing, tariffs, patents, and related questions.

I have included thermodynamics among the engineering sciences because I believe that it should be taught to engineers from an engineering point of view. An acquaintance with the scientific fundamentals will already have been secured from the course in physical chemistry.

Some may quarrel with my inclusion of elements of electrical engineering and unit operations of chemical engineering in the engineering sciences. They are, of course, applied sciences based on the more fundamental sciences, but I regard an elementary knowledge of these two subjects as essential tools that the student needs before he can begin to attack any comprehensive problem in chemical engineering without too much lost motion. On this basis I include them among the subjects to be covered before the final year. This is particularly true of the unit operations—those fundamental operations of heat transfer, fluid flow, distillation, filtration, and the like which underlie the whole of chemical industry and which are now firmly established as the backbone of modern chemical engineering courses.

Before coming to the work of the senior year there is one point which I should like to mention about which there has been considerable argument. It is my belief that all the courses in basic science should be definitely considered as preparatory to the later engineering courses and the subject matter chosen with this end in view. This means that in mathematics, physics, physical chemistry, and so forth, emphasis should be placed on those facts and principles which can be directly utilized in the work of succeeding courses, and material of purely theoretical interest should be omitted. This strictly practical point of view seems to me to be entirely in line with the general concept of the curriculum already presented. Furthermore the engineering student is very impatient with those things which appear to him to have no practical value. It is important to maintain his interest by concentrating on those parts of a given subject which can be applied and to illustrate the application continually by suitable problems.

It is difficult to realize this type of course in practice as it means close coöperation between the engineering and science departments and frequently necessitates special courses for the chemical engineers.

The senior year of the proposed course is to be quite different from the preceding one. In the first three (or four) the emphasis was on individual subjects. The elements of each subject had to be learned without particular reference to their interrelationships or their significance to any specific engineering problem. The disorganized individual threads must somehow be integrated, or woven into some kind of a unified and ordered pattern. I believe that the best way to do this is to shift the emphasis entirely from individual subjects and center all the work of the senior year around a small number of comprehensive problems or projects, selected as far as possible to represent real engineering situations like those encountered in practice and to involve as many of the fundamentals previously studied as is feasible.

I would have no lecture courses, or formal laboratory

courses or any specific assignments in textbooks. There would be class meetings for purposes of discussion. The students would consult many books, not because certain passages were assigned to be learned, but on their own initiative because they needed some information for the solution of a problem. Subject matter is decidedly secondary. There must be no attempt to cover ground as this will defeat the whole purpose of the scheme.

THE COMPREHENSIVE PROBLEM

I shall digress for a moment to explain in a more concrete way what I mean by a comprehensive problem. The usual problem given in a specific course such as physical chemistry or unit operations is one of very limited scope and with the conditions all well defined by the instructor. In fact, he strives hard to define and qualify the problem so carefully that a minimum of questions will be raised in the student's mind. This is, of course, quite the opposite of any real engineering problem which is poorly defined at the start and immediately raises a host of questions. This type of problem, which I will call the simple problem in contrast to the comprehensive one, can generally be readily solved by formulas given in the textbook or by data obtained from a handbook. Most of the thinking has already been done by the instructor, and it is probable that he is the one who gains the most from it, rather than the students. However, this type of problem is useful, and, I believe, essential to the process of learning the fundamentals of a particular subject. We should recognize that the solution is little more than a routine procedure once the principles expounded in the text are read and understood.

The comprehensive problem has a simple and well-defined objective. On the other hand, the trail leading to the objective is not only very ill-defined but there are apt to be a large number to choose from, most of which lead to dead ends, necessitating frequent retracing of steps to make a fresh start. In other words, it cannot be solved simply by reference to formulas or handbooks. It is broad enough so that it must be attacked from various angles and with a variety of tools. It must be analyzed to reduce it to a number of simple problems. This process will give plenty of opportunity for the student to exercise judgment and ingenuity and to bring together data and principles from hitherto unrelated fields.

Comprehensive problems should be real (as distinct from artificial) problems of a practical character, and this presupposes that the engineering teacher has sufficient contact with industry so that he can devise such problems. This is another story beyond the scope of the present paper.

Let me illustrate the comprehensive problem by a concrete example. Assume that a plant is using a certain solvent which is simply evaporated into an air-stream and lost. It is desired to determine the feasibility of recovering the solvent in a form available for re-use. This is a statement of a comprehensive problem in a very general form. The ultimate objective is simple and clear, but the means to reach the objective are very obscure. There is no formula that one can find anywhere which will furnish an answer to the problem. Such a problem will completely baffle any student who is used to having his thinking all done for him and his problems all analyzed and dished up in such finished form that all he has to do is to turn a crank and grind out a result.

Obviously, this is a very broad problem, and we must narrow it so that a student may reach some conclusion in a limited amount of time. The first problem assigned might be to decide on the general outline of the process that is to be tentatively selected for further study. This will involve a consideration of the fundamentals underlying the condensation of vapor in a mixture of vapor and non-condensable gas to a liquid. Several general methods such as refrigeration, compression and cooling, absorption in a liquid absorbent, or adsorption on a solid adsorbent might be used. A decision in favor of one of them must be made and supported by facts. The details cannot be entered into here, but it should be evident that the solution will involve the bringing to a focus of knowledge from several different fields and is far from a routine matter. In the course of his analysis of the comprehensive problem the student will set for himself many simple problems of the type he has learned to do in specific courses. The difference, and it is a very important one, is that now he sets up the problem himself. Consequently, it means much more to him than if the instructor had done it. For example, in the course of weighing the advantages and disadvantages of the various processes for solvent recovery, he will set himself the problem of calculating the power requirement to recover a gallon of solvent by the compression process, assuming various specific conditions. This is information that he must have in order to arrive at an intelligent decision. The final solution of the problem will be a report setting forth the various possibilities and then a recommendation of one of them accompanied by all the supporting arguments.

Having chosen the process in general outline, another comprehensive problem would be to choose the detailed conditions of operation—pressures, temperatures, concentration, rates of flow, and so forth. This will involve many simple problems in physical chemistry and in the unit operations of chemical engineering. The final problem will be a matter of economic balance to arrive at an estimate of the cost of recovery, which is the ultimate objective. This is necessarily a very sketchy outline but, I hope, sufficient to convey a general idea of the type of problem I have in mind.

CURRICULUM OF THE SENIOR YEAR

As a specific proposal, it is suggested that there be not more than four technical courses in the year, each centering around a different type of comprehensive problem or project. I will outline these briefly as follows.

(*1*) *A Calculation Course Based on the Economic Balance Type of Comprehensive Problem, an Example of Which Has Been Given.*—There would be no laboratory work in this course and the two or three class meetings a week would be informal and devoted to the discussion of the many questions that arise as the work on the problem proceeds. From four to eight problems would suffice for the year, and they should be selected to involve as many of the subjects studied in the preparatory years as possible. It is also well to start with relatively simple problems because problems of this type will be a new experience for the students, and there will be a great deal of floundering until they have acquired a little confidence. Problems like the annual contest problem for the Student Chapters of the American Institute of Chemical Engineers are well suited to the needs of this course.

(*2*) *Plant or Equipment Design Project.*—The problems of this course will be solved mainly on the drawing board. At least the final result will appear in this form, though much of the time will be devoted to searching for data and making calculations. The problems may be individual, or the whole class may work on the same problem. Both systems are used, but I prefer the latter. The use of individual problems places too heavy a burden on the instructor.

Two or three problems are all one can hope to undertake and they can often be advantageously correlated with problems used in Course 1. After the flow sheet and general operating conditions for some process have been arrived at by the work of Course 1, the problem can then be carried further under this second course. It may involve either the selection and arrangement in the plant of standard equipment, or it may take the form of the detailed design of some piece of special equipment.

(*3*) *A Laboratory Project.*—This is simply a comprehensive problem, but one for which some of the necessary data are lacking, and the objective of the project is to supply these data. For example, in the case of the solvent recovery problem already used as an illustration of problems under Course 1, it may be that the calculation of the size of a heat exchanger or of an absorption tower is hampered by lack of data on rate coefficients or data on pressure drop due to flow or on vapor pressure of the solution of the vapor in the absorbent and the object of the project is to secure the data by experiment.

The project does not need to be of a research character like the ones just outlined but may involve a test on some equipment. The nature of the problem is not important, as long as the student himself has to plan the method of attack to reach the objective, and as long as it involves some application of fundamentals previously learned.

Frequently, the original statement of the problem is quite broad and indefinite and the student, in consultation with the instructor, must narrow it and make it more specific. This, in itself, is excellent experience. The laboratory project also gives useful experience in searching literature, formulating a plan of attack, designing and operating equipment, and interpretation of experimental results. Throughout the whole course of the work, the reliance on fundamentals is stressed and driven home on every suitable occasion.

Our laboratory project course runs for eight hours a week throughout the year. The students have individual problems, and each is assigned to a project advisor. There are no regular class meetings and no regular meetings between the student and advisor, but it is the responsibility of the latter to keep in close touch with the student's work, to help him when he comes to an impasse, to see that he has the facilities he needs, and to keep him steered in the right direction.

(*4*) *Reports.*—Much has been written and said on the subject of the inability of the average engineering graduate to write clear, concise, readable reports. The only way to help this situation is to give the student practice in writing under guidance and criticism. Courses in English may help a little but they do not get to the root of the matter. From my own experience in teaching students to write reports, it is clear to me that the major difficulty is not with the grammar or the sentence construction but simply lack of ability to organize their material. This can be learned only by experience.

In order to write a good report, one has to have something from his own experience to write about—something that is vivid and alive for him. I find that the laboratory project "fills the bill" very well. In my own case, I require four reports during the year on the project. The first one is due a few weeks after the students have started their work and is a short one giving a statement of the problem, its relation to a broader problem, and an outline of the proposed method of attack. It is surprising how difficult it can be to write a paper which is apparently so simple to organize. These reports are criticized severely and must often be re-written.

After about three months of work on the project, a progress report is due and everything done in this period has to be digested, organized, and presented in good form. This is also severely criticized and gone over individually with the student. A second progress report about the middle of the second term summarizes the first one and then presents the subsequent progress. A final, bound report is due at the end of the year, and this must be a complete report on the whole problem.

One or two oral reports are also desirable to give the students some experience in this form of expression. Here again the laboratory project furnishes the subject matter.

The program for undergraduate instruction in chemical engineering which I have outlined is somewhat idealistic in that it has not yet been wholly worked out in practice. It indicates the direction in which we are working to shape the course given at Yale. There are many practical difficulties in the way, but we have

made distinct progress. What I have in mind may, perhaps, be comparable to the four-year course followed by a fifth year of graduate work as now practiced at some schools; but since about eighty per cent. of our graduates do not return for advanced work, I believe it is better to incorporate these ideas in the undergraduate course and devote the graduate years primarily to training in research.

TEACHING CHEMICAL ENGINEERING UNIT PROCESSES *from the* QUANTITATIVE ASPECT

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THE study of chemical engineering unit processes has to do with the design, construction, and operation of large-scale equipment in which at least one chemical reaction takes place and possibly one or more physical transformations. The principal accent is on the design rather than the construction or operation.

No engineering subject, chemical or otherwise, can be based upon anything but a quantitative study. Unfortunately for the teachers of chemical engineering, very little is known about the quantitative aspects of the design of equipment in which a chemical reaction takes place.

It should be realized, however, that the basis of the study of unit processes is exactly the same as the study of unit operations; in other words, heat or energy transfer and fluid or material flow. All problems on heat transfer or fluid flow involved in the design of equipment in which a chemical reaction takes place may, therefore, be classified as unit process problems.

The mere fact that a chemical reaction takes place in such equipment complicates a problem in heat transfer or fluid flow. It is extremely difficult at the present time to calculate satisfactorily the amount of heat transfer that will occur, for example, in equipment before it is actually constructed and operated, even though in this equipment no physical transformation or chemical reaction takes place. The problem becomes more difficult when a physical transformation does take place and becomes almost impossible once the chemical reaction starts.

It is possible, however, to propose problems involved in unit process studies that may not be very important from the design standpoint but at least are interesting from the academic standpoint. It is felt, furthermore, that the solving of these relatively simple problems is important from the student's standpoint, because an early start in the development of the quantitative side is desirable.

Certain industrial stoichiometric problems make satisfactory unit process problems. An excellent example of this is contained in an article by Lewis and Ries.[1] The authors are interested in the heat transfer in a sulfur dioxide converter. They desire to calculate the temperatures, and other conditions for the oxidation of sulfur dioxide to sulfur trioxide.

The converter which they are considering operates as follows. The entering gases are passed through a preheating coil at the top of the converter and then through intermediate heating coils between layers of catalyst until they reach the bottom where they are allowed to enter the converter, passing up through the successive layers of catalyst and out the top. There are valves present in the lines so that any heating coil may be by-passed if the calculations indicate it advisable. The amount of flow through any heating coil can be controlled. The same heating coils act as cooling coils as far as the gases inside the converter are concerned.

Their data indicate that the conversion is consider-

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[1] *Ind. Eng. Chem.*, **17**, 593 (1925); **19**, 830 (1927).

ably above ninety per cent. when the temperature is maintained below 400°C. Above this temperature the conversion falls until it is quite low at 525°C. It is quite evident that a rough range of temperature of operation should be between 400°C. and 530°C., remembering that the speed of reaction caused by the catalyst is considerably greater at the higher temperature.

Lewis and Ries have taken an eight per cent. sulfur dioxide gas as the basis of their operation and have assumed a practical conversion of sixty per cent. for the first layer of the catalyst at the bottom maintaining a maximum temperature of 530°C.

The oxidation of one mole of sulfur dioxide to one mole of sulfur trioxide liberates 22,500 C.H.U. On a basis of one hundred moles of gas, the heat capacity would be 760 C.H.U. per degree. This would mean that 0.6 of 8 or 4.8 moles of sulfur trioxide would be formed in the first layer of catalyst.

$$4.8 \times 22{,}500 \text{ C.H.U.} = 760 \text{ C.H.U.} \times 530°\text{C.} - C_1,$$

the temperature of the outlet gas. The simple solution of this equation results in the temperature of $C_1 = 388°$C.

Lewis and Ries assume that the conversion in the second layer rises from sixty to ninety per cent. Looking on their chart it will be found that a temperature of 480°C. is necessary for this ninety per cent. conversion. The eight moles of entering sulfur dioxide $\times (0.9 - 0.6) \times 22{,}500 + (530 - 480°) \times 760$ C.H.U. gives the amount of heat that must be absorbed or 92,000 C.H.U. Dividing the 92,000 by 760 gives a temperature drop of the gases of 121°C. The 121°C. subtracted from the 388°C. gives a temperature of 267°C., the inlet temperature of the gases to the second layer of the catalyst. It can easily be seen that this simple process could be carried on throughout the various layers of catalyst and the necessary temperatures calculated. From these temperatures it is evident how much cooling is desired in each section. The desired temperature may be maintained by permitting the requisite amount of gas to go through each cooling coil. It is not claimed that this is a calculation often used by the designer of sulfur dioxide converters, but it is evident that the student of chemical engineering will have a much better idea regarding the basic design of oxidation catalyst chambers if he is able to understand the theory behind the solution of this problem.

Material balance on a process often has to be made in order to redesign equipment and bring about higher efficiencies. Problems involving material balances and heat balances are usually classified under the heading of industrial stoichiometry. Nevertheless, they can be used satisfactorily as problems in unit processes. An excellent example of this type of problem is one involving a material balance on the chamber sulfuric acid process as shown by Lewis and Radasch in their book entitled "Industrial Stoichiometry."

The authors first calculate the sulfur efficiency of the entire process by a material balance. They determine also by material balances the per cent. of total acid in the Glover tower, the per cent. of acid returned to the Glover tower, the per cent. and amount of water in the exit acid from the Glover tower, and the amount of water necessary to be fed in as water to the lead chambers.

Oftentimes the student can obtain sufficient data by doing simple experiments in the laboratory that will permit him to determine equilibrium conditions for certain reactions, such as simple esterifications, and at the same time obtain certain fundamental knowledge regarding the design of the necessary reaction chamber.

An example of this would be the design of a mixing chamber in which we desire to have prevail at all times equilibrium conditions in the esterification of acetic acid with ethyl alcohol, using sulfuric acid as the catalyst.

It would be interesting, first of all, to calculate the equilibrium conditions for the particular concentrations of acetic acid and ethyl alcohol remembering, of course, that it is always advisable to select a reasonable excess of ethyl alcohol in order to bring to as low a figure as practical the concentration of acetic acid present in the equilibrium mixture. If the free energy values are not available, rough values can be determined by simple experimentation in the laboratory. If such is the case, it will be necessary, first of all, to study the influence of sulfuric acid on the rate of reaction. Such experiments are always run in industrial laboratories prior to the designing of the equipment.

It is appreciated, of course, that the calculation or determination of free energy values and the corresponding equilibrium constants are, strictly speaking, physical chemistry or chemical thermodynamics and not chemical engineering. However, it is such problems as these that the chemical engineer working in industry must be familiar with, and they are absolutely essential in the design of proper equipment providing, of course, equilibrium conditions for the particular case in question are not already available in the plant.

Furthermore, it is felt by many of our educators that the determination of free energy values and the use of these values are oftentimes so complicated that the younger student will not be able to comprehend them. This may be true in elementary courses but it certainly is not true in senior courses.

Once the proper concentration of catalyst has been determined and the resulting equilibrium conditions have been found, simple mixing equipment can be set up in the laboratory to determine the actual time necessary to bring about this equilibrium. It is recognized, of course, that such laboratory equipment does not represent in its behavior the larger scale equipment. On the other hand, it will approximate it to a sufficient extent to justify the calculations.

It is realized that once such a mixture has been brought to equilibrium and there is present a satisfactory catalyst, the mixture can be run into a fractionating column and during the process of fractional distillation one hundred per cent. yields will result,

based on the component acetic acid, which is present in the lesser amount. Such an experiment can be tried with a laboratory scale fractionating column, the overall efficiency of which is known. It is then quite possible to predict what would happen in a larger scale column of a definite size with a definite number of plates and with a definite plate efficiency.

Again, it should be pointed out that the designers in industry do not use this method but are forced to rely on pilot plant equipment or even full size units in order to determine accurately the design factors. Nevertheless, it can be maintained that such problems as the one given above are of interest and are distinctly worthwhile from the student's standpoint.

Attempts have been made on various occasions to select problems involved in the cracking of petroleum to produce gasoline that might be suitable for academic purposes. It is, of course, quite true that it is possible to estimate roughly the overall heat transfer in certain portions of a cracking coil or pipe still. These calculations, however, are based on heat transfer formulas and do not take into consideration any specific effect of the chemical reactions involved in the cracking zone.

Egloff and Nelson in their paper entitled "The Modern Cracking Process" given before the Chemical Engineering Congress of the World Power Conference in June, 1936, and published in the *Transactions of the American Institute of Chemical Engineers* described the characterization factor for petroleum. This factor K is determined by dividing the cube root of the average boiling point in degrees Rankine by the specific gravity at 60°F. They state that this factor shows a fair constancy throughout the boiling range for a number of crude oils. For others it may either increase or decrease in the higher boiling ranges. This factor depends upon the proportion of paraffin and aromatic hydrocarbons present.

Watson, Nelson, and Murphy[2] have found that a fair empirical correlation exists between this characterization factor and the viscosity-gravity relationship at a given temperature.

Egloff and Nelson show in their article that petroleum can be characterized by other factors such as the aniline point, the hydrogen content, the molecular weight, critical temperature and pressure, thermal expansion and compressibility, specific heat, and so forth.

In order to be more specific, these authors have indicated roughly how the effect of temperature influences the rate of reaction and how the characterization factor mentioned above affects the cracking rate; also, how the average boiling point affects this rate. Unfortunately, these studies are not complete enough at the present time to justify the use of problems based on these results, although it is quite possible for the instructor to propose simple problems of this nature that may have some pedagogical value.

A. M. Fairlie in his recent book on sulfuric acid has shown some highly practical, though empirical, methods for the design of the Gay-Lussac tower. He states that with the four to two per cent. niter concentration, thirty to sixty seconds of contact are necessary for a gas velocity of three to one foot per second.

An average niter loss of three per cent., based on the sulfur burned with an average time of contact for the gases of forty-five seconds and a free space in the packing of fifty per cent. would normally require fifteen hundred cubic feet of actual packing space per one thousand cubic feet of chamber exit gas per minute. The gas is measured at 55°C. This is equivalent to twelve hundred cubic feet of packing space per one thousand cubic feet of six per cent. sulfur dioxide burner gas per minute, the gas measured at 100°C. or approximately one thousand six hundred forty cubic feet of packing space per one thousand cubic feet of burner gas per minute, the gas at standard conditions.

The ratio of the diameter to the height varies from one-half to one-sixth. One-fifth and one-sixth are better values for practical design. The diameter of the tower should be kept around ten feet providing the volume of gas used is not very large. For large volumes this diameter is impractical and can be increased to as high as thirty feet. In the latter case a ratio of diameter to height of one-half should be taken as otherwise the tower would be far too high from an economic standpoint.

If the desired velocity is two feet per second and thirty-five seconds time of contact seems to be sufficient, then the packed region in the tower would be seventy feet high, or a total height of eighty feet. In such a case it would be necessary to have two columns in series, each about thirty-five feet high.

In calculating the height, as indicated above, the time of contact is multiplied by the velocity, and the number of towers is indicated after examination of the resulting figure. Allowance must be made at the bottom and top for free space and also for the thickness of the floor.

The cross-section of the tower can be determined by multiplying the necessary cubic feet of packed space per one thousand cubic feet of exit gas at the actual temperature leaving the apparatus per minute by the number of one thousand cubic feet units of this gas and dividing by the total height of the packed space. The method of calculation of the inside diameter is obvious.

The same author has shown the method of designing the Glover tower. He states that twenty-eight to thirty-one per cent. free space (cross-section) can be realized with the modern packing. Twenty to twenty-five square feet of cross-section per one thousand cubic feet of gas per minute, while the gas is at standard conditions, should be allowed. Furthermore, seven hundred to eight hundred cubic feet of contents per one thousand cubic feet of gas per minute, the gas at standard conditions, should be used. Again it must be remembered that allowance should be made for the top and bottom sections where there is little or no activity and for the space occupied by the walls.

Other examples could be given of how problems could

[2] *Ind. Eng. Chem.*, **47**, 1460 (1937).

be made illustrating the design of equipment in which chemical reactions take place, but the examples which are mentioned should be sufficient. It is hoped that industry will be able to supply the necessary data for the development of a great many problems of this nature because it is felt that a quantitative treatment of unit processes in our classes is absolutely essential.

THERMODYNAMICS *in the* UNDERGRADUATE CURRICULUM *in* CHEMICAL ENGINEERING*

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IN THE minds of some people, chemical engineering education has been assumed to be of the practical type, excluding theoretical studies and indirect reasoning. That this is not a true picture of the situation will be evident to anyone who reads the papers in this symposium. The following discussion of thermodynamics for students of chemical engineering shows that modern training in chemical engineering is not concerned with a mass of isolated facts and empirical formulations, but attempts to train the student in mathematical and exact methods of reasoning leading to accurate numerical conclusions, thus making him sure-footed when he meets new problems in uncharted territory in industry.

In recent years the curriculum-builders in most chemical engineering schools have realized the inadequacy for their students of the usual thermodynamics course as taught to mechanical engineers. They have also come to believe that the course in chemical thermodynamics is not quite what chemical engineering students need, although the content of chemical thermodynamics may be said to be the basis of chemical engineering thermodynamics. What was needed was the combination of the useful material and methods developed by the chemists, physicists, and mechanical engineers and the addition thereto of the graphical mathematics already used by chemical engineers. As no textbook is yet available, few of the smaller schools have yet attempted to offer such a course.

After a chemical engineering student has graduated, he usually looks forward to work in equipment design and process development. In this work it is highly important that he be able to calculate the exact thermodynamic relationships involved. Mere heat and material balances are insufficient in processes where important pressure changes occur; what he needs is energy and material balances, usually followed by the laying out of an economic balance. In such cases, a complete thermodynamic study is necessary before the method and the detailed specifications of equipment giving the lowest annual cost of production can be specified.

Obviously it is not good educational practice to teach students the thermodynamics of the ideal gas and follow it up by saying that the use of the resulting equations will be twenty per cent. in error if the pressure is 500 atmospheres. If the student is to use thermodynamics intelligently instead of blindly, he must be able to find out for himself how much error is introduced by assuming that the gas is ideal. As a starting point, he has pressure-volume-temperature tables, or, what is the same thing in more convenient form, compressibility factor tables. By little-known but extremely useful methods of graphical and numerical differentiation of these tabulated values, he can obtain curves or tabulated values of all of the important partial derivatives, sometimes called partial differential coefficients, as functions of pressure, volume, and temperature. These partial derivatives are then useful for substitution in rigorous thermodynamic equations.

One successful sequence of courses tied together by thermodynamics gives the student his first exposure to thermodynamics in the first semester of his junior year as part of his physical chemistry course. In that course he will study the first law and the second law and acquire an understanding of such quantities as entropy and enthalpy, and will solve problems with the aid of

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these quantities. He will also be introduced to partial differentiation of thermodynamic equations and will come to realize how he can convert an equation containing quantities difficult or impossible to measure directly into an equation containing only easily measurable or already known and tabulated quantities, or those obtainable by differentiating tabulated data. The physical chemistry course is followed in the second semester of the junior year with a course called fluid dynamics. In this course no attempt is made to touch on the energy situation in regard to chemical reactions or on the thermodynamics of solutions. The course begins with an exhaustive study of the thermodynamic information which can be extracted from pressure-volume-temperature tables and compressibility factor tables for various gases. Allan Ferguson[1] discusses the various quantities which can be so extracted and, starting with P-V-T tables for some gas or liquid, makes the following tangible suggestions, modified and amplified by the present writer:

(1) Calculate the compressibility $(\partial V/\partial P)_T$, by differentiating a table of volumes down a single temperature column. Then for every place in the column occupied by a volume one can get a numerical value for $(\partial V/\partial P)_T$. These values of $(\partial V/\partial P)_T$ can then be plotted or tabulated as varying with P at any single value of T. A complete table or family of curves could be made by repeating the operation on each temperature column of the original P-V-T table.

(2) Calculate the thermal dilation $(\partial V/\partial T)_P$. This is exactly analogous to the procedure under (1). The table is differentiated horizontally instead of vertically, and a complete table can be worked out without difficulty.

(3) The isothermal reversible work done in compressing the fluid from one pressure to another is given by $W = \int_{P_1}^{P_2} P(\partial V/\partial P)_T dP$. This convenient form is obtained directly from $W = \int_{P_1}^{P_2} PdV$ by the use of a general law for partial differential equations: $dV = (\partial V/\partial T)_P dT + (\partial V/\partial P)_T dP$. The quantity W is obtained by the graphical integration of either $W = \int_{P_1}^{P_2} PdV$ or $\int_{P_1}^{P_2} P(\partial V/\partial P)_T dP$, and it is a good idea to have the student do both and see if he gets the same value; it will give him confidence in the accuracy of his differentiation.

(4) The heat given off during an isothermal reversible compression: $Q = \int_{S_1}^{S_2} TdS = -T\int_{P_1}^{P_2} (\partial V/\partial T_P)dP$. The tabulated quantities found in (2) are substituted here, and a graphical integration performed. The student may be asked to show that for ideal gases the quantities under (3) and (4) are equal.

(5) Having determined the values for (3) and (4) for the same gas at the same temperature, the difference is the change in internal energy. For ideal gases, this will be zero, as $(\partial V/\partial P)_T = 0$.

(6) The quantity $(\partial P/\partial T)_V$ is difficult to obtain directly by graphical differentiation of a table of volumes as functions of T and P, because it involves hunting for identical volumes diagonally across the table. However, having sets of values of $(\partial V/\partial T)_P$ and $(\partial V/\partial P)_T$ found under (1) and (2), the quantity is obtained by substitution of these in $(\partial P/\partial T)_V = -(\partial V/\partial T)_P/(\partial V/\partial P)_T$.

(7) From the rigorous thermodynamic equation $(\partial C_P/\partial P)_T = -T(\partial^2 V/\partial T^2)_P$ at T = const. $\int_1^2 \partial C_P = -\int_1^2 T(\partial^2 V/\partial T^2)_P \partial P$. The term $(\partial^2 V/\partial T^2)_P \equiv [\partial(\partial V/\partial T)_P/\partial T]_P$ and numerical values are obtained by graphically differentiating a constant pressure line of $(\partial V/\partial T)_P$ values with varying temperature. Thus if the constant pressure specific heat is known at one pressure, it can be calculated for any other pressure at the same temperature provided P-V-T data are available. In this way a whole table of C_P values as functions of T and P can be built up. The student may be asked to show that C_P is not a function of pressure in the case of the ideal gas.

(8) Having a complete set of values of C_P as calculated under (7), the corresponding complete set of C_V values can be calculated from the results of previous computations by substitution in the rigorous equation: $C_V = C_P + T(\partial V/\partial T)_P^2/(\partial V/\partial P)_T$. For the ideal gas, the student may be asked to show that $T(\partial V/\partial T)_P^2/(\partial V/\partial P)_T = R$.

(9) Entropy tables may be constructed by the use of the previously-gathered tabulations.

$$\text{At } T = \text{const.}, \int_{S_1}^{S_2} dS = -\int_{P_1}^{P_2} (\partial V/\partial T)_P dP.$$

$$\text{At } P = \text{const.}, \int_{S_1}^{S_2} dS = \int_{T_1}^{T_2} (C_P/T)dT.$$

By graphical integration, it is easy to obtain values of relative entropy for each space in the table, the other variables being, as usual, P and T. By plotting curves of these entropy values, constant entropy lines may be drawn, and from the intersections may be read values of P or T for the construction of a table with constant entropy columns. From this table and previously made tables it is not difficult to get numerical values for (10) and (11) and to make numerical solutions of such problems.

(10) The rise of temperature over a specified pressure range in a reversible adiabatic compression may be calculated by the aid of previously computed quantities by substitution in the rigorous equation $(\partial T/\partial P)_S = T/C_P(\partial V/\partial T)_P$. From this, at S = const., $\int_{T_1}^{T_2} \partial T/T = \int_{P_1}^{P_2} 1/C_P(\partial V/\partial T)_P \partial P = \ln T_2/T_1$.

(11) The difference between reversible adiabatic and

[1] FERGUSON, ALLAN, "The mechanical properties of fluids," Blackie and Son Ltd., London, 1925, p. 15.

isothermal compressibilities: $(\partial V/\partial P)_S - (\partial V/\partial P)_T = T/C_P(\partial V/\partial T)_P^2$.

If compressibility factor tables are used instead of P-V-T tables, it is necessary to know what is meant by the compressibility factor. In "Chemical Engineers' Handbook," edited by Perry, $C = PV/P_0V_0$ in which P_0V_0 is at 0°C. and 1 atm. If the gas can be assumed to be ideal at 0°C. and 1 atm., $C = PV/RT_0$. To calculate such quantities as $(\partial V/\partial P_T)$ and $(\partial V/\partial T)_P$ for substitution in the previously presented equations, it is only necessary to partially differentiate $V = RT_0C/P$, and it turns out that

$$(\partial V/\partial T)_P = RT_0/P(\partial C/\partial T)_P$$

$$(\partial V/\partial P)_T = RT_0/P[(\partial C/\partial P)_T - C/P]$$

Thus the student may differentiate the compressibility factors instead of volumes, and make the substitutions as indicated.

In addition to the above, tables and curves of enthalpy can be computed. The fugacity is also derived, values computed, and uses developed. The law of straight-line flow of compressible fluids is derived, and then simplified for the non-compressible case. Then by analogy the corresponding equations for turbulent flow are developed by use of the Reynolds number. All of this work is accompanied by problem assignments illustrating the use of the equations developed. Seldom is there any deviation from the policy of never developing an equation without giving an application in a numerical problem.

The fluid dynamics course is followed in the senior year by a course called Chemical Engineering Thermodynamics. In this course the material usually given to mechanical engineers is given briefly, but thoroughly, during the first few weeks. The preparation in previous courses enables the students to assimilate these methods rapidly, and to make accurate computations for processes involving steam boilers, turbines, gas engines, and gas compressors. The students are required to construct enthalpy-concentration charts for solutions with one volatile component from thermodynamic data. These are known as Merkel charts and are useful in solving multiple effect evaporation problems in the concurrent unit operations course. They also study the construction of enthalpy-concentration charts for two volatile components. These charts are useful in column distillation problems, but it is unfortunate that little of the fundamental data are reported in the literature. It is planned that the students shall determine some of the missing quantities in the physical chemistry laboratory course and then use the results in the construction of these so-called Ponchon diagrams. Then the students are given a thorough understanding of free energy and related quantities and are required to solve problems involving metallurgical and other chemical reactions.

Having had continuous exposure to the various phases of thermodynamics for two years, the students graduate with confidence that they can successfully attack any thermodynamic problem for which physical data are in existence, and can approximate solutions even when some of the data are missing.

In many chemical engineering curricula there is much less thermodynamics than outlined above. The trend, however, is toward very thorough and comprehensive work in thermodynamics with plenty of practice in its accurate application.

The CHEMICAL ENGINEERING LABORATORY—OBJECTIVES *and* EQUIPMENT*

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IT IS difficult to define chemical engineering or the type of work done by a chemical engineer. Perhaps the best broad generalization is to say that a chemical engineer is concerned with production. To date most of the chemical engineer's opportunities have been with production in the so-called process industries such as petroleum refining, sulfuric acid, caustic, plastics, artificial silk, rubber, and a host of others. The chemical engineer's interest in production can be classed under three important headings, namely:

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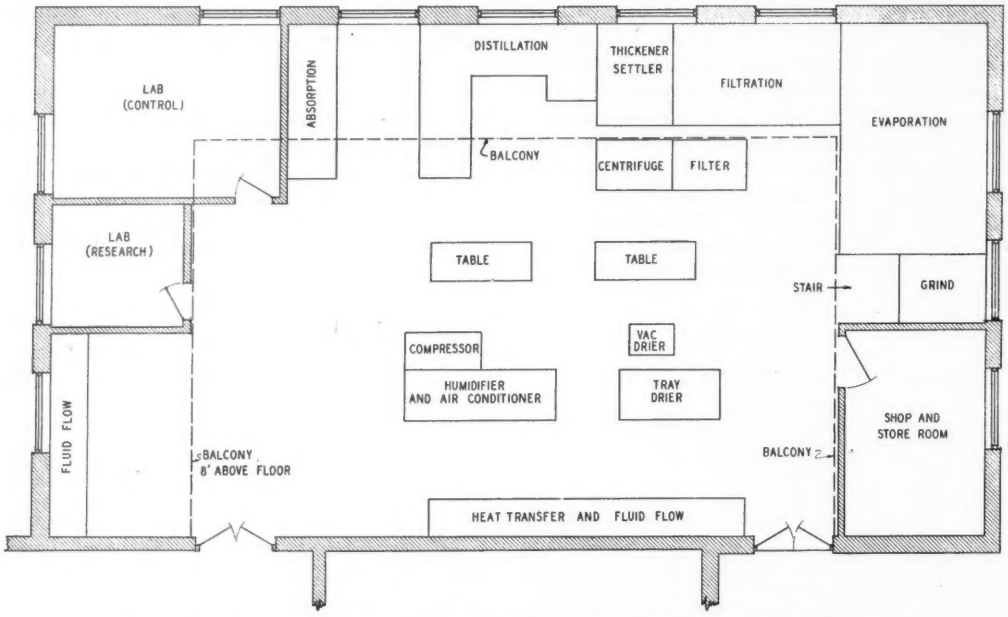

FIGURE 1.—LAYOUT OF CHEMICAL ENGINEERING LABORATORY, UNIVERSITY OF VIRGINIA

operating and control of processes; development of new or more efficient processes; development of equipment. The last two are interrelated and are often spoken of as engineering research. Usually the chemical engineer has to do with the equipment necessary for producing desired changes in the materials in the process rather than the actual changes produced. He is often far more interested in creating the proper environment in which a chemical or physical change can take place than in the chemistry involved. For example, in petroleum refining the chemical engineer designs cracking stills, and rectifying equipment to be used with them, so that the proper conditions of pressure and temperature can be maintained in each step of the process to give optimum yield. Further he must design the equipment to handle the products in proportion to their bulk. The chemist has determined the chemistry involved and has pointed the way to the operations entailed, but it is the engineer's job to provide the proper equipment and sequence of operations to make the process economically sound. This means that the chemical engineer must understand the characteristics of the materials being handled (the chemistry involved) and the characteristics of equipment so that an efficient mechanism can be devised (the engineering involved). In the chemical engineering laboratory the work is designed to add to the student's knowledge of equipment and to integrate it with his previous knowledge of chemistry and the other fundamental sciences.

There are two rather distinct yet interdependent objectives in this work. One is to use the laboratory to illustrate principles, to learn new facts, and to develop familiarity and skill in the handling of process equipment, auxiliaries, and tools. The other is to use the laboratory to give the student the opportunity to develop an engineering viewpoint. By giving him a challenging problem the opportunity is provided for initiative, resourcefulness, and experience in working out a solution. To these ends experiments are devised which attempt to satisfy both of the aims simultaneously.

The easier of these objectives to meet is the first. We can teach new facts with heat exchangers, evaporators, filters, and so forth, in much the same way that knowledge about oxidation, polymerization, and precipitation is illustrated in the chemistry laboratory. Some experiments are developed with this idea uppermost. Principles of chemical engineering are discussed in the classroom and numerous problems are solved. In the laboratory these principles are illustrated by applying them to a problem involving actual equipment. When the student has seen the application of facts and theories, he may reach the second objective and visualize new combinations and ways of doing things. To stimulate this attitude in the mind of the student we set up a problem in which he analyzes an engineering situation and develops his own solution. In actual laboratory practice both objectives are combined in most experiments. This point will be illustrated later by a few references to laboratory exercises.

In order to be a good engineer a man should possess good judgment, which can only be developed through experience. Thus it follows that the more rounded the experience the better the judgment. Good judg-

ment in engineering depends upon the proper evaluation of all the variables which enter into a process, including economic variables such as power cost and labor as well as technical variables of pressure, temperature, and rate of reaction. If we can acquaint the student with a few simple engineering problems involving operating equipment, where his good judgment for their solution is required, then we have given him experience. His ability to judge is thereby cultivated and he should gain confidence. When a fundamental principle is illustrated incidentally in the attack on a problem, experience and confidence are gained in applying theory to practice.

Included in the two broad objectives are the following particular aims (no attempt having been made to weigh their relative importance):

To use engineering equipment and become familiar with construction and operation.
To connect and repair equipment.
To evaluate performance.
To determine best testing points and methods.
To record data and analyze them.
To illustrate theory.
To interpret data in the light of theory.
To analyze a situation and plan a method to obtain the data necessary to evaluate it.
To illustrate research methods.
To use reference texts and journals.
To determine the best type of equipment for a given operation.
To determine the best sequence of operations in a process.
To determine the limits of applicability of experimental data.
To determine the best way of presenting data and results.
To write a good report.

These aims should be kept in mind in the planning of an experiment.

The development work in any of our large industrial chemical concerns is typical of the application of the principles of mathematics, physics, and chemistry which are the backbone of chemical engineering. Usually such development divisions are designed to obtain rate and equilibrium data, design data for equipment, performance data, proper sequence of operations, cost analyses, and to apply theory. Obviously the reporting of the methods used for obtaining data and the interpretation of them are of utmost importance. Thus if our chemical engineering laboratory is organized so that its equipment can be used to determine the same type of thing that is desired by the commercial laboratory, experiments can be devised to reach the objectives discussed. The direct illustration of theory which is not so important in the commercial laboratory can be pointed out, of course, in the school laboratory work. This is the philosophy behind most of our efforts in this work.

The equipment used to realize our objectives is varied. The use and study of instruments for test purposes (that is, for determining temperature, pressure, rate of flow, and so forth) is fundamental. They are studied alone or observed in connection with the testing of a piece of process equipment. The basis of study of process equipment is the unit operations of chemical engineering. Equipment to illustrate the theory and operation of the following unit operations is in general use: flow of fluids, flow of heat, evaporation, humidification processes, drying, distillation, absorption, extraction, mixing, settling, crushing and grinding, screening, filtration, and centrifuging. Single pieces of equipment for such processes as nitration, esterification, fusion, autoclaving, and so forth, are also used; they illustrate the combination of the unit operations in one apparatus. Equipment varies in the different laboratories. All test equipment such as

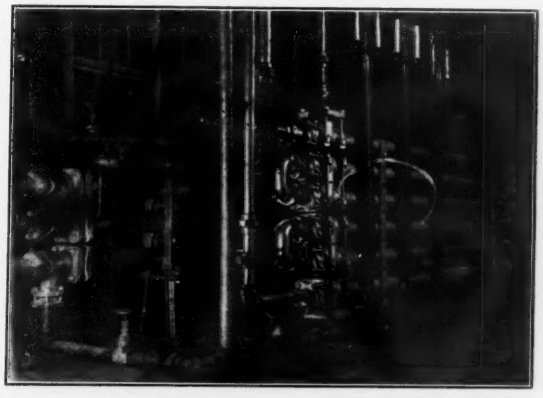

FIGURE 2

gages, pyrometers, and hydrometers can be purchased and are standard; but thermocouples, pitot tubes, orifices, and manometers are usually made up in the laboratory shop. Except for pumps, most of the fluid flow equipment is built and assembled to suit the convenience of the particular laboratory. Much of the heat transfer equipment can be fabricated in the shop, and the same applies to the humidification, drying, absorption, mixing, settling and extraction equipment. The other equipment is generally built to specification or is small commercial size. In general the equipment approximates pilot plant size. Also it is important to have good shop facilities to make changes and for proper maintenance.

Figure 1 shows the floor plan of the layout of a laboratory to be installed at the University of Virginia. A balcony is shown on three sides of the laboratory. This indicates the type of space and arrangement which is ideal for this type of laboratory. The plan, of course, is diagrammatic. For example, the space marked distillation will have placed in it several stills, fractionating columns, and condensers.

Instead of presenting a detailed list of types of equipment used for the various unit operations and processes

mentioned, I shall give a few typical examples of equipment and experiments.

Fluid flow is generally the first subject studied in the laboratory. Equipment for this illustrates characteristics of flow, measurement of flow, pumping, and general handling for both gases and liquids. It is designed to show the effects of temperature, channel size and shape, viscosity, and density on turbulence and friction. Various measuring devices such as orifices, venturi meters, pitot tubes, and displacement meters are studied, both individually and in connection with other unit operations. For example, in an experiment on humidifying it is necessary to measure both the flow of gas and liquid. Here the proper adaptation and handling of fluid flow measuring instruments is required to obtain humidification data. In fact, for the study of almost every unit operation it is necessary to measure material or fluid flows. To a somewhat smaller extent the same is true for flow of heat. To study means of pumping fluids, reciprocating, centrifugal, and gear pumps for liquids and fans, blowers, and compressors for gases are used. Often performance tests of such apparatus are made under varying conditions and in connection with the study of other fluid flow problems.

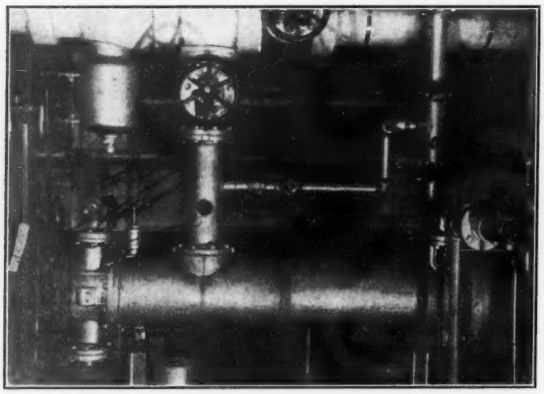

FIGURE 3

Figure 2 shows a laboratory set up for flow of heat experiments. This shows two banks of double pipe heat exchangers. The rear bank is used to heat liquid by means of steam, and the front bank is used to cool this hot liquid by a cooler liquid flowing in the inside pipe. Thermometers or thermocouples or both can be used to observe temperatures. Two orifices connected to the manometers serve to measure the fluid flow, and weight tanks are used to calibrate the orifices and to measure steam drips. The third manometer shown is used to determine the head loss due to friction for liquid passing through the system. This set up is chosen for illustration because it is useful not only for determining the rate of heat transfer, but also for study of fluid flow. To illustrate the use of this equipment for both fluid flow and heat flowstudies, I shall give two experiments.

First, for fluid flow, the problem is stated to the student as follows: A double pipe heat exchanger using pipe and return fittings of the same size and kind as in the laboratory set up is to be built for a chemical plant. The exchanger will be fifteen feet long from flange to flange (this distance is about five feet longer than the experimental unit) and will have ten passes. It is to be used to cool aniline flowing in the annular space from 120°F. to 70°F. For various rates of flow of aniline find the yearly cost for pumping, assuming a power cost of 1.5 cents per kw.-hr., an over-all motor and pump efficiency of sixty per cent., and an operation of twenty-four hours per day, three hundred days per year, which also calibrate the orifice in the annular space line. Within what limits will these results apply if eighty per cent. glycerol is substituted for the aniline?

The student must plan to obtain the data necessary to find the cost of operation. Apart from the calibration of the orifice, which is asked for directly, the only experimental data required for solution of the problem is the resistance of the return fittings. Usually this fact eludes the student for quite some time. All data necessary to determine the cost of operation are available through application of the theory in our texts, except for the equivalent length of the return fittings. One assumption is necessary—that the pipes are clean commercial iron pipe. The student plans his experiment, deciding how and when to make readings and what data are necessary. After the runs and calculations are made a report is written.

With the same equipment another problem involving heat transfer may be given as follows: Hot water from a process is available at 175°F. for heating a colloidal solution (properties essentially equal to that of water). The hot water flows in the annular space and may vary from ten to fifty gallons per minute depending on plant operation. The solution enters the heater at a rate of fifteen gallons per minute and at 60°F. The final temperature of the solution is to be 170°F. and can be brought up to this temperature by steam if necessary in a separate exchanger connected in series. How will the rate of heat transfer vary for different rates of flow, and what portion of the total heating of the solution must be done by steam? Also determine how heat transfer in this equipment is related to fluid friction losses.

Again the student must plan the experiment to get the data needed and to decide on the method of presentation of the results.

From such exercises we attempt to cover the objectives mentioned earlier. In each case there is a simple engineering situation postulated, with the idea of bringing in several principles. A preliminary report is required outlining the student's plan for performing the necessary work. The theory involved is outlined and after performance of the experiment the complete report is made. After a number of these problems it is hoped that the student will gain experience in the attack of a simple engineering problem involving actual

equipment and in presenting results in good form and showing their limitations, and also gain confidence in his ability to apply theory to practice.

Figure 3 shows a four-pass tubular heat exchanger. This contains about fifty square feet of heating surface and is used in connection with an evaporator and other laboratory equipment. Figure 4 shows a large iron plate-and-frame filter press, each frame offering about 3.5 square feet of filtering area. Generally only two or three frames are used at one time.

A typical experiment using this filter press may be stated as follows: A slurry of Cil-o-Cel is to be filtered in a plate-and-frame press. The slurry is such that when $^1/_2$ liter is filtered through a 50-mm. Büchner

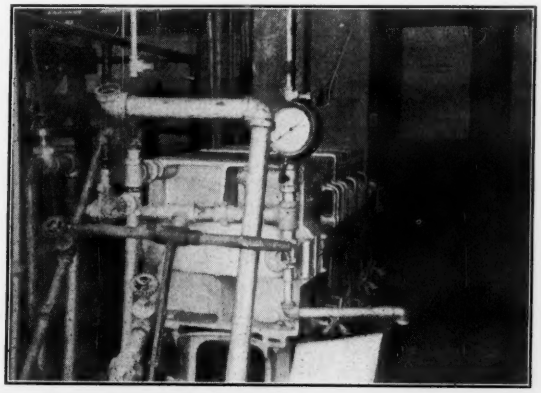

FIGURE 4

funnel with 15 inches to 20 inches vacuum a pad $^1/_4$ inch thick will be formed. The slurry also contains 35 g. of $KMnO_4$ per 100 gallons. The frames are to measure 18 inches × 18 inches (the laboratory press size is different) and are to be either one or two inches wide. The press is to operate under constant pressure. The pressure for filtration may be anywhere from ten to thirty pounds gage. Assume a dumping, cleaning, and assembling time of ten minutes for the whole press, and a cost for this work of one dollar per hour. Other labor and overhead to be figured at 0.2 cents per square foot of filtering area per hour. The press will be operated twenty-four hours per day. The cake is to be washed until the washings are colorless and then dried by air blowing for eight minutes. Recommend the pressure and frame size (one- or two-inch) to be used. Compare the filtration results with the filtration theory.

Figure 5 shows a still and auxiliary equipment used for high-vacuum distillation or steam distillation. Its capacity is thirty gallons per batch. Usually, distillation equipment consists of a still with bubble cap rectifying column and the necessary condensers. Size and design vary, but generally a column nine inches or more in diameter and at least ten plates are used. Continuous column operation is accomplished by proper modification of batch equipment.

Figure 6 is a flow sheet of a small sized commercial vertical-tube basket-type evaporator with auxiliary equipment. Figure 7 is the view of the basement floor assembly of this evaporator, showing the salt catch and drip tanks.

It should be emphasized that these pieces of equipment are not used merely to illustrate commercial types but have been used to determine operating data, design data, or data for process analysis. Equipment of this type is flexible and is continually being modified. It should be subject to test by all types of measuring devices, for obtaining quantitative rather than qualitative data. The industrial development laboratories use such equipment for investigations. It should be designed with flexibility in mind so that it is available for research, and several experiments devised for it. Also this equipment should show its proper use in any process in which it may be used, rather than its use in some particular process. Occasionally however, these pieces of equipment are used to make a desired product, but in general they are studied from the standpoint of their all-around use in industry and their performance under varying conditions.

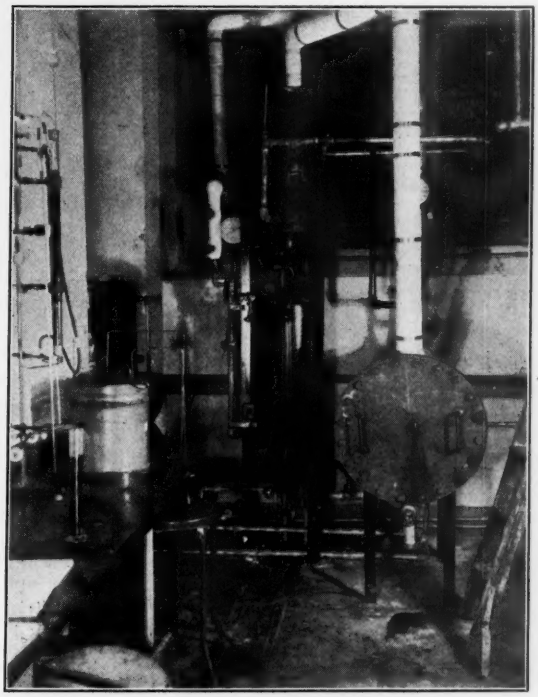

FIGURE 5

Equipment for studying a process is of two types. Several pieces of unit operation equipment may be used in series, as in making an economic balance on a process for reclaiming ferrous sulfate from pickling bath liquor. Or a single piece of equipment can be

used where two or more unit operations take place, as in the nitration of benzene and subsequent reduction and distillation of the product. The latter type, like jacketed kettles and crystallizing pans, give the necessary equipment for the so-called unit processes of sulfonation, nitration, esterification, and so forth.

An example of the proper coördination of unit operation equipment in a process is to set up apparatus for

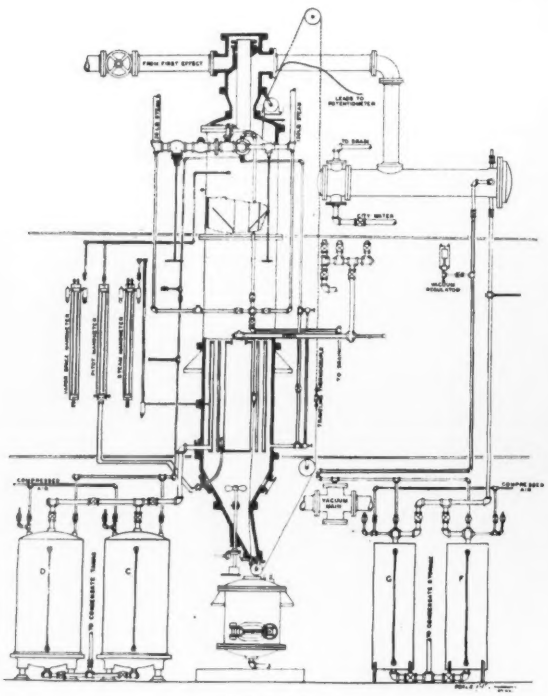

FIGURE 6

salt production. The salt is dissolved in water, pumped and filtered, the solution evaporated and solid salt finally recovered. Such an experiment is often called a salt run. The proper coördination of equipment is stressed as is the organization of data, systematic analysis of results during the progress of the run, and heat and material balances over the entire system. A whole class usually runs such an experiment over a period of eighteen to forty-eight hours.

A word should be said about more advanced chemical engineering laboratory work. In some project courses or in research courses for undergraduates, a problem is selected or assigned involving the finding of some new data or to extend some principle to fields previously unexplored. These problems may be studied for one or more semesters, and are really engineering research problems. They are problems in connection with theory, plant design, process layout, or economic balance studies. To illustrate, Figure 6 is taken from a senior report on a problem to determine the temperature distribution and boiling level of liquid in a vertical-tube basket-type evaporator, where all circulation is due to the boiling of the liquid. A traveling thermocouple is shown in the drawing, which could be raised or lowered as desired and temperatures determined at various places. Another senior substituted a small pitot tube for the thermocouple to try to measure the

FIGURE 7

liquid velocity in the tube. Such variables as boiling point of the solution, liquid level, and temperature drop can be related to velocity of flow through the tubes by data from these experiments. It is often only a small step from this type of undergraduate laboratory work to the beginning of an advanced program of graduate research on characteristics of plant equipment.

I hope that by the few examples of types of equipment and kinds of problems mentioned, the objectives of teaching in the chemical engineering laboratory have been pointed out. The experiments must be properly set, the equipment flexible, and the aim of the instructor clear in order to realize the objectives.

We find ourselves, in consequence of the progress of physical science, at the pinnacle of one ascent of civilization, taking the first step upwards out on to the lowest plane of the next. Above us still rises indefinitely the ascent of physical power—far beyond the dreams of mortals in any previous system of philosophy.—FREDERICK SODDY

OBJECTIVES *in* GRADUATE TRAINING *for* CHEMICAL ENGINEERS*

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THE objective of any university training is primarily to help the student toward a fuller, more useful and satisfactory life. The special objective of professional training is to prepare the student for his professional life.

A quarter of a century ago it was hardly possible to do more in the way of special chemical engineering training than to assemble a program of courses in chemistry and the older branches of engineering and to dignify such a hodge podge as a curriculum in chemical engineering. Nearly all the professors in the new field had been trained as chemists, and the only specialized courses offered were in industrial chemistry, which pretended to nothing more than a qualitative description of industrial operations that were frequently obsolete. Chemical industry itself rated experience highly and distrusted theory (probably because the theory then available, even to the trained man, was grossly inadequate to handle actual plant problems) and relied upon chemists mainly to determine the quality of materials by analysis.

As knowledge of physical chemistry became organized and was used to predict how processes might be controlled in commercial operation as well as in the laboratory, progressive industry reversed its field and demanded men trained in quantitative theory and the numerical application of such theory to the problems of design and operation. Up to then, there had been some ground for the claim that chemical engineering was merely a branch of chemistry. But with the recognition that one of the major functions of the chemical engineer was the control of processes, and that this control is obtained primarily through physical means, which can be divided into simple unit operations common to the various industries as first formulated by Dr. A. D. Little in 1915, chemical engineering became a distinct branch of engineering, which might as well have been called "process engineering." In fact, the definition of chemical engineering proposed by the American Institute of Chemical Engineers Committee on Chemical Engineering Education, A. D. Little, Chairman, and adopted by the Institute, stated that chemical engineering had its foundation on those unit operations which in their proper sequence and coördination constitute a chemical process as conducted on the industrial scale.

In order to coördinate these unit operations in an efficient and proper manner, the engineer must understand thoroughly not only the unit operations themselves and the process which is to operate, but the effect of different variables on the operations and process. This is a big order demanding a thorough training in physics, physical chemistry, and mathematics, as well as the unit operations, and the chemistry of the process itself, but finally, and most important, trained ability in the quantitative application of this specialized knowledge to commercial industrial operations.

The adequacy of a four-year collegiate course for any engineer, and particularly for a chemical engineer, has long been questioned. Many proposals and some attempts to establish five or six-year courses have been made but with little success as there are less than four per cent. as many students in the fifth year of undergraduate work as in the fourth year.[1] There has, however, been a definite trend toward increased graduate study in all branches of engineering. Of 2040 engineering students enrolled in their first year of graduate work, three hundred forty-two or seventeen per cent. were in chemical engineering, and of three hundred sixty-four engineering students who had progressed beyond their first year of graduate work, one hundred fifteen or thirty-four per cent. were in chemical engineering.[2] Although the proportion of chemical engineers in the group working toward a master's degree is similar to that in other branches of engineering, the proportion working for the doctorate is far higher among chemical engineers.

Chemistry draws six times as many candidates for the Master's and twelve times as many for the doctorate as chemical engineering.

Graduate instruction can thrive only in strong, well equipped schools and three institutions enrol forty-two per cent. of all candidates for the Master's degree and sixty-two per cent. of all candidates for the doctorate in chemical engineering.

The policy of mass education in this country requires

* Contribution to the Symposium on Chemical Engineering Education, conducted by the Division of Chemical Education at the ninety-fourth meeting of the A. C. S., Rochester, N. Y., September 7, 1937.

[1] BISHOP, F. J. *J. Eng. Education*, **26**, 312 (1935).

[2] WHITE, A. H. "Chemical engineering congress of the World Power Conference (1936)," Percy Lund, Humphries & Co., Ltd., London, **1937**, Vol. 4, p. 93.

our schools to shape their curricula to suit the best interests of the average student. Since only a minority of our high-school graduates enter college, our so-called secondary schools do not primarily prepare students for college. The programs of the engineering schools are in the long run controlled by those who employ their graduates, and as long as industry demands three men from the four-year course to one with five years or more training, so long will our undergraduate courses be adjusted primarily for the man who enters industry at the end of four years.

If the four-year program is successful in turning out trained engineers, why should such a graduate return for further study? If the four-year program is not successful and the graduate returns for further study simply to supplement and repair the deficiencies of his four-year course, why should such four-year graduates find such ready and satisfactory employment in industry?

TABLE 1

COMPARISON OF TYPES OF EMPLOYMENT FOR ALL 1920–1930 GRADUATES

	Five years after B.S.	*Ten years after B.S.*
Total Individuals	498	120
Plant operation, development and engineering	43.1%	41.3%
Research	19.9%	19.2%
Sales	9.5%	13.7%
Teaching (including graduate study)	10.6%	12.0%
Analytical laboratory	5.9%	4.6%
Miscellaneous	10.8%	9.2%

Without considering the existence of such inadequate four-year courses which need supplementing to repair the deficiencies therein; let us consider whether the four-year graduate pursues his post-graduate work with somewhat different objectives than the undergraduate.

Perhaps the best approach to discover what these different objectives may be, is an analysis of the type of work in which these differently trained men find themselves a number of years after graduation. A comprehensive study by Professor White covering graduates in the period 1920 to 1930 is about the only authentic record of this kind and is probably representative of current conditions.[4]

Table 1 is taken from Professor White's paper where it appears as Table IVa, and clearly indicates the large proportion of chemical engineers directly connected with plant work.

All graduates, particularly those with post-graduate training, are extensively employed in semiworks development from two to five years after entering industrial employment, but appear to advance from the semiworks development into what is classified as general engineering. This is probably a normal advancement along technical and executive lines in which the individual is concerned more with the economics and success of commercial operations than semiworks development. In the following tabulation plant operation is listed separately, and the more technical engineering and development work listed as engineering.

In Table 2 which represents the average type of employment from five to ten years after receiving the first degree, graduate study has been omitted as it drops to three per cent. in the fifth year and decreases thereafter and may be regarded as preparation for, rather than a type of employment.

The first three columns of Table 2 are based directly on Professor White's analysis. The first column (headed B.S.) includes all graduates whether they continued their studies further than the bachelor's degree or not. The second column (headed M.S.) includes all students who completed one or more years of graduate studies after receiving the B.S. The third column (headed Ph.D.) includes all students who completed two or more years of graduate studies.

The last three columns of Table 2 have been recalculated, and are based respectively on those students who received the bachelor's degree only and went no further with their scholastic studies, those who complete one year only of graduate study, and the last column those who completed two or more years of graduate study.

Comparison of columns 4 and 5 of Table 2 clearly indicates the similarity in employment of graduates with bachelor's and master's degrees only. Clearly such graduates should be trained similarly, primarily for plant operation, engineering development, research and sales; as about seventy-five per cent. of all graduates who do not complete more than five years of chemical engineering training are found in these types of employment. Teaching is a relatively minor occupation; and analytical work negligible.

TABLE 2

AVERAGE TYPE OF EMPLOYMENT OF CHEMICAL ENGINEERING GRADUATES OVER THE PERIOD FIVE TO TEN YEARS AFTER THEIR FIRST DEGREE

Type of work	*All graduates with training indicated*			*Graduates who ceased scholastic training with*		
	1 B.S.	2 M.S.	3 Ph.D.	1 B.S.	2 M.S.	3 Ph.D.
Operation	21%	18%	8%	23%	24%	8%
Engineering	19%	19%	22%	19%	19%	22%
Research	18%	24%	33%	15%	20%	33%
Sales	14%	10%	2%	16%	14%	2%
Teaching	10%	13%	26%	9%	8%	26%
Analytical	4%	3%	0%	4%	4%	0%
Miscellaneous	13%	11%	8%	14%	11%	8%

Since graduates with one year of post-graduate training ("masters") engage in the same types of work as those without such training ("bachelors") there must be some advantage in this additional training to compensate for the increased time and expense. Recent conversations with employers of our graduates indicate that employers are willing to pay more for "masters" than "bachelors" because they find "masters" quicker to take hold and to develop into valuable men. The "masters" are reputed as being better able to apply their knowledge to obtain quantitative practical results. Even though the "bachelors" seem to under-

[4] WHITE, A. H., *Trans. Am. Inst. Chem. Engrs.*, **27**, 221 (1931).

stand the process thoroughly, they are less able to determine the quantitative effect of changes in conditions, or to apply their theoretical knowledge in their daily work.

Referring again to Professor White's data, this enhanced value of a master's training was apparently not so generally recognized by employers ten years ago, as at that time the median starting salary for masters was the same as for bachelors in all types of employment except in analytical or research laboratories and sales, in which the median salary was two hundred dollars, three hundred dollars, and four hundred dollars more respectively, or approximately the same as bachelors were receiving in their second year of employment. However, the "master" soon overtook the "bachelor" and five years after his M.S. (six years after his B.S.) the "master" median earnings were equal to those of the "bachelor" the following year (seven years after his B.S.) in all types of employment except teaching and sales. And from that time on the master's earnings continued to increase faster than those of the "bachelor."

Ten years ago it took three years for the master to catch up with the bachelor who started in industry a year earlier, and five years to get a year ahead of the bachelor. At the present time the master is not handicapped in salary at the start, as employers seem to appreciate his enhanced value.

As has been indicated, the chemical engineer must be thoroughly trained in the application of physics, chemistry and mathematics to plant problems, while other branches of engineering are based on the application of mathematics and various branches of physics and do not include chemistry. An adequate theoretical groundwork for chemical engineering requires at least one-half more preparation than for other branches of engineering, and the application is correspondingly more complex.

In the standard four-year course, we find chemical engineering students devoting approximately the same time to mathematics and physics as do other engineering students, and also devoting as much or more time to additional chemistry beyond that taken by other engineering students, as to mathematics and physics combined.

With all this additional theoretical preparation necessary, it is clear that the application must be slighted unless more time is allowed; but a study of chemical engineering curricula showed in most cases actually less[5] time devoted to chemical engineering than to studies in other branches of engineering.

The objective of graduate training in the first year of graduate study for chemical engineers should be thorough training in the quantitative application of mathematics, physics, and physical chemistry, as expressed in the unit operations and thermodynamics to numerical problems of the process industries. This can be done effectively only by the "case method," that is, actual commercial plant-type problems which are solved numerically, corrected, and thoroughly explained.

In studying chemical engineering in this manner, which may be called the "comprehensive problem method" and which is equivalent to the "case method" used in teaching law, the student actually is trained not only in the application of his principles but also is given the best possible review of the principles themselves. In fact this method is relied upon almost entirely to give training in principles as well as application, in the "case method." The "comprehensive problem method" extends the student's knowledge of fundamental theory and by its practical use gives him that essential confidence.

Exactly what industry is chosen for the various case studies makes little difference as it is the application of theory and not the industry which is being studied.

This fact is clearly evident by the attitude of employers, particularly the larger companies which employ a large number of technical men, who have little or no interest in what field the student has learned to apply his fundamentals provided he has mastered their application. Graduate students who have specialized in evaporation of heavy chemicals are employed for process work by the petroleum industry as readily as those who have specialized in metallurgy, paper, gas, or petroleum. To the modern employer the subject of the doctor's thesis is of less interest than its quality.

Therefore, the instructor should be free to choose his examples from his own experience and field of specialization. In other words, the course must be adjusted to the experience and capacity of the instructor, rather than the instructor being assigned to a particular course which should cover a definite syllabus or field as is necessary in teaching mathematics, physics, chemistry, unit operations, and thermodynamics.

In fact there should be no objection to different instructors in different courses selecting similar problems from the same industry as each will have his own manner of treating the problem and the students will thereby appreciate the different approaches possible to the same problem. Instruction of this nature can be adequately handled only by competent experienced engineers in close contact with industry, and is most easily given in the form of process design problems in which numerical answers are obtained for the sizes, capacities and efficiencies of a commercial plant designed by the student.

These problems should be presented only in general terms so that the student learns to analyze the problems to determine the assumptions that must be made and the data that must be obtained for their solution. It is this ability and experience in analyzing or "setting up" the problem so that it may be solved directly that makes the engineer a success. A few handbooks and a high-school education are usually sufficient to solve such a problem after it has been analyzed into its component parts and the solution indicated.

[5] PARMELEE, H. C., Chairman, "Report of Committee on Chemical Engineering Education," *Bulletin of Proceedings 17th Semi-Annual Meeting, A.I.Ch.E.*, No. 31, p. 19–25 (1925).

If any choice of industries is to be made for the selection of these plant problems, preference should be shown those industries which employ or are likely to employ the larger numbers. Professor White's tabulation indicates that more than seventy per cent of all graduates entering industry do so in the following fields in the order listed: petroleum, organic, metallurgy, heavy chemicals, rubber, gas and coke, paint and varnish, or pulp and paper.

Those students who continue their graduate studies for more than one year and usually finish the doctorate, (Table 2) are found largely in the fields of research, engineering or teaching. In so far as salary is concerned on the average the "doctor" starts out on a parity with the "master," who has had two years' head start in research, plant development or general engineering, and maintains a superior position, particularly in research work.

In training chemical engineers for the doctorate, the same objective of trained application of theory must be preserved, but in addition advanced theory in physical chemistry, physics, mathematics, unit operations and thermodynamics are also required to fit the graduate to take a leading position in research and teaching as well as professional engineering.

Research work in preparation of the thesis is regarded as a method of training the graduate in the application of theory to research, which is a most important complement to the training in application of theory to plant problems provided in the first year of graduate study.

There is actually more of a break or change in viewpoint between the training required for the Ph.D. and M.S. than there is between the M.S. and B.S. All graduate students should be required, and the more competent seniors should be encouraged, to elect a number of comprehensive problem courses in which the student is trained in the application of theory. The more advanced courses in theory designed primarily for Ph.D. candidates should be reserved for those advanced students who have passed the master's requirements or the comprehensive examinations required of applicants for the doctorate.

To summarize, the objectives in graduate training for chemical engineers are:

1. For all graduate students a group of courses giving thorough comprehensive numerical training in the application of theory, as summarized in unit operations and thermodynamics, to commercial plant problems as evident in process design; the object of which is the teaching of application of theory to commercial problems and not the teaching of any industrial process itself.

2. In addition for Ph.D. candidates advanced theory in class room and seminar in physical chemistry, physics, mathematics, unit operations and thermodynamics, and the application of such theory to plant problems; by means of thesis research training in the application of theory to research, which may be of a laboratory, or semi-works nature, or preferably based on commercial sized equipment when such is suitable and available.

3. In all cases the "case or comprehensive problem method" is absolutely essential.

USE OF CALCIUM ACETATE IN THE DEMONSTRATION OF A SUBSTANCE SHOWING A NEGATIVE COEFFICIENT OF SOLUBILITY

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IN A RECENT issue of THIS JOURNAL,[1] Bateman and Fernelius describe the use of cerous sulfate for the demonstration of a substance showing a negative coefficient of solubility. They mention calcium chromate, calcium hydroxide, and calcium sulfate as other substances which show this behavior, but which do it ineffectively as a class demonstration because of the small amount of solid precipitating out.

A very striking demonstration of this phenomenon of decreasing solubility with increasing temperature may be shown by the use of calcium acetate. The handbooks give varying data for the solubility of the monohydrate, ranging from 43.6 to 52 g. per hundred grams of water at 0°C. to 29.7–34.3 g. for its solubility at 100°C. In any event, the change in solubility for the one hundred-degree range is something of the order of over ten grams.

The experiment may be carried out most effectively as follows. A nearly saturated solution of the chemically pure salt is prepared. The almost crystal clear solution is then placed in a large Erlenmeyer flask and heated. The temperature need not go above 80°C. before there is definite indication of the formation of a white precipitate that can be observed easily throughout a large lecture room. If the flask is now placed under the cold water tap and swirled, the entire precipitate will go back into solution, restoring the original clear liquid. The system responds quickly to these temperature effects so that the entire demonstration may be carried out in less than five minutes.

The advantage that calcium acetate has over cerous sulfate is that it is more easily obtained in most chemical laboratories.

[1] BATEMAN, L. A. AND W. C. FERNELIUS, J. CHEM. EDUC., **14**, 315 (1937).

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KEEPING UP WITH CHEMISTRY

Photographic action of artificial radio-elements. CH. GROVEN, J. GOVAERTS, AND G. GUÉBEN. *Nature*, **141**, 916–7 (May 21, 1938).—A sheet of iridium, which had been irradiated with neutrons, slowed down in paraffin, was placed directly on the emulsion of a photographic plate. After twenty-one hours of exposure, the plate, upon development, showed distinct photographic blackening. When similar sheets of iridium which had not been irradiated were placed on the plate, no blackening was observed. Another plate exposed for forty-eight hours to radiophosphorus, placed about one millimeter from the emulsion, was distinctly darkened. "These first attempts show undoubtedly the photographic action of artificially produced radio-elements." M. E. W.

The determination of small amounts of cerium in copper welding wire. E. PACHE. *Chem.-Ztg.*, **62**, 102 (Feb. 5, 1938).—Dissolve ten g. of the alloy in aqua regia, boil off the nitrogen oxides, add one cc. of ten per cent. ferric chloride solution to which an excess of ammonium hydroxide had been added, boil, let settle for half an hour, and filter. The precipitate consists of ferric hydroxide, cerium hydroxide, and antimony oxyhydrate. Wash with water made slightly ammoniacal, wash off from the filter paper, dissolve in dilute hydrochloric acid and dilute the solution to two hundred cc. Introduce hydrogen sulfide for twenty minutes, whereby all the copper and antimony are precipitated. Filter off the sulfides, wash with water containing hydrogen sulfide and boil off the hydrogen sulfide. Add a few drops of hydrogen peroxide during the boiling, boil down to one hundred cc., and filter off any precipitated sulfur. Render the clear filtrate faintly ammoniacal, boil, and carefully add five grams of solid oxalic acid which dissolves the precipitates of iron and cerium hydroxides. On prolonged boiling cerium precipitates as a white solid. Let settle, warm, filter, wash free from iron by means of water containing one per cent. of oxalic acid, dry, heat to red heat, and weigh as cerium dioxide. The pure compound is white. Traces of rare earth oxides of the cerium group will color it light to reddish brown. L. S.

New compounds of silicon. R. SCHWARZ. *Ang. Chem.*, **51**, 328–31 (June 4, 1938).—Heating silicon tetrachloride in a tube in an atmosphere of argon yields $Si_{10}Cl_{22}$ which is the inorganic compound with the largest chain yet known. The similar thermal treatment in an atmosphere of hydrogen instead of argon yields $Si_{10}Cl_{20}H_2$. Both compounds are thick fluids at room temperature. During the decomposition of the second compound these reactions take place:

$$Si_{10}Cl_{20}H_2 = 4SiCl + Si_3Cl_8 + Si_3Cl_7H - HCl$$
$$Si_{10}Cl_{20}H_2 = 4SiCl + 2Si_3Cl_8 + H_2$$
$$Si_{10}Cl_{20}H_2 = 4SiCl + 2SiHCl_3 + Si_4Cl_{10}$$
$$Si_{10}Cl_{20}H_2 = 6SiCl + SiHCl_3 + Si_2Cl_6 + HCl + SiCl_4$$

L. S.

A new titrimetric determination of phosphoric acid. W. RATHJE. *Ang. Chem.*, **51**, 256–8 (May 7, 1938).—For analysis for phosphoric acid the acid solution is treated with potassium iodide and titrated with a bismuth solution of known concentration forming bismuth phosphate

$$Bi^{+++} + PO_4^{---} = BiPO_4$$

At the endpoint any excess of bismuth ions react with iodide ions forming insoluble bismuth oxyiodide which indicates the endpoint by its red color.

$$Bi^{+++} + I^- + 2OH^- = BiOI + H_2O$$

L. S.

The determination of antimony in aluminum alloys. E. PACHE. *Chem.-Ztg.*, **62**, 149 (Feb. 26, 1938).—*Alloy contains antimony, lead, and two per cent. copper.* Dissolve one gram of the alloy in 20 cc. of hydrochloric acid, oxidize with 5 cc. of three per cent. hydrogen peroxide and heat until the solution is clear. Dilute with 50 cc. of water, add 20 cc. of twenty per cent. sodium sulfide solution and boil until no more sulfur dioxide is evolved. Dilute with 100 cc. of water and titrate with $N/10$ potassium bromate using methyl orange as indicator. *Alloy contains antimony, lead, and manganese.* Start as given above. Following the reduction with sodium sulfite and the boiling off of the sulfur dioxide dilute with 200 cc. of water, add 40 cc. of manganese sulfate, and titrate with $N/10$ potassium permanganate to faint pink. The same alloy may also be analyzed as follows. Dissolve one gram of the alloy in ten per cent. sodium hydroxide solution, dilute with 30 cc. of water, make acid with sulfuric acid and concentrate by boiling until heavy white fumes are produced. Let cool, dilute with 50 cc. of water, add 20 cc. of hydrochloric acid, and warm until clear. Add 200 cc. of water and 40 cc. of manganese sulfate and titrate with $N/10$ potassium permanganate to faint pink. L. S.

The detection of lead from tetraethyl lead and observations on the volatility of tetraethyl lead. H. SIEBENECK. *Chem.-Ztg.*, **62**, 188–9 (Mar. 12, 1938).—Dimercaptolthiodiazol in one per cent. solution is recommended for the detection of dangerous amounts of lead in waste waters from industrial installations. The limit of detection is three milligrams of lead per liter. The reaction can be used also for the detection of lead in hydrocarbons. Tetraethyl lead when mixed with hydrocarbons is volatile at ordinary temperatures. L. S.

Lignin a source of valuable chemical raw materials. ANON. *Sci. News Letter*, **33**, 379–80 (June 11, 1938).—Lignin, long considered one of the objectionable ingredients of wood fiber is shown by the United States Forest Products Laboratory and the University of Wisconsin to be convertible into: "a well known organic solvent, wood alcohol; a new lacquer solvent called propyl-cyclohexanol; two compounds having possible use as thickening and toughening agents for varnish; and a clear glassy resin, extremely adhesive, which may prove very useful as a plastic material." Hydrogenation is one treatment by means of which the lignin is transformed into these valuable forest resources. The importance of such work is appreciated when one realizes that lignin comprises twenty to thirty per cent. of woody parts of plants. The method described is estimated as able to render seventy per cent. of the lignin useful for industry. B. C. H.

Hydraulic brake fluids. R. R. FULTON. *Ind. Eng. Chem.*, **30**, 422–7 (Apr., 1938).—Hydraulic brakes on automobiles were first introduced in 1922 and are now quite general. For years the castor oil-ethyl alcohol type was about the only one used. Castor oil is the only commercially available substance that is suitable to act as a lubricant or impart body to brake fluids, since it does not have a deleterious action on rubber. Due to its high solidification point and increasing viscosity it cannot be used alone. Fluids used must have little change of viscosity with temperature, have a stable composition, no action on rubber or metals, low volatility, low leakage, good miscibility with fluids generally used, and low cost. Lack of action on rubber eliminates a great many organic compounds as a diluent for castor oil. Among these are chlorinated compounds, aromatic hydrocarbons, mineral oils, distillates from wood except methyl alcohol, acetones except diacetone, ketones, pine oils, and turpentine. Alcohols

above b. p. of ethyl, have an increasing swelling and softening action on rubber. Glycols have been used to reduce softening action of propyl and butyl alcohols on rubber, but the use of glycols increases the problem of miscibility. A number of the brake fluids are described, and a suggested list of tests to determine the suitability of a given fluid is described. D. C. L.

Test-tube support. I. A. KOTEN. *Chem. Analyst,* **27,** 42 (May, 1938).—When it is necessary to heat several test-tubes for making comparisons, as in testing carbohydrates, a test-tube support can be made by punching holes in a metal can cover. A cover five and a quarter inches in diameter fits 600- or 800-cc. beakers and holes for nine test-tubes can be conveniently punched. These holes can be numbered if desired. This device is most serviceable in physiological chemistry. D. C. L.

Vapor pressure lowering visualized. R. E. DUNBAR. *Chem. Analyst,* **27,** 47 (May, 1938).—A simple apparatus consisting of two bottles with rubber stoppers and a U-tube connecting them can be readily assembled. Water is placed in one and an equal volume of a concentrated solution of a non-volatile solvent in water in the other. It is then set aside in a warm room for several days when the difference in level is quite noticeable. This is much more effective than placing a beaker of water and one of solution under a bell jar, where both beakers usually lose in volume, with the condensation of moisture on the walls of the bell jar. D. C. L.

Electrolytic production of ammonium nitrate. ANON. *Chem. Industries,* **42,** 657 (June, 1938).—An abstract of a process reported of Kobozew and his co-workers is given in the *J. Chem. Ind.* (*U. S. S. R.*), **17,** No. 19 (1937), which involves following reactions.

$$4H_2O = 4H_2 + 2O_2$$
$$NH_3 + 2O_2 = HNO_3 + H_2O$$
$$HNO_3 + NH_3 = NH_4NO_3$$
$$2NH_3 + 4H_2O = NH_4NO_3 + 4H_2 + H_2O$$

Time of operation, pH requirements, current density, catalyst concentration, and anode materials are also discussed. A. T. B.

More penetrating agents. ANON. *Ind. Bull. of Arthur D. Little, Inc.,* **138,** 4 (July, 1938).—Until a few years ago only three types of cleansing and wetting agents were known; namely, soaps, saponin, and turkey-red oil. Nearly all cleansing was done with soaps unless the water was hard. Then a limited amount of cleansing was done with the vegetable material, saponin, or with crude soap-bark from which it is obtained. Turkey-red oil is castor oil treated with sulfuric acid. It is used as a wetting agent more than as a cleanser, especially where watery dressings are carried into greasy leather or cloth. Recently a considerable number of new types of wetting and cleansing agents have been synthesized to extend and supplement the three old types. These new types are sulfates or in some cases sulfonates, combination of sulfuric acid with organic materials. Sulfated alcohols produce the "Gardinols" and "Lorols." Sulfated esters produce "Igepon A" and sulfated amines, "Igepon T." These work well in hard water and even in the presence of acid. They are even useful in shampooing, it is said. "Ultra-wet," developed by the Atlantic Refining Company, has for its base a particular cut of petroleum oil. It is used as a wetting agent and as a detergent. "Santomerse," announced by the Monsanto Chemical Company, has an aromatic chemical base. These are used for general cleansing purposes, as spreading agents, for insecticides, and in textile processes and for flotation of ores. G. O.

An industry survives. ANON. *Ind. Bull. of Arthur D. Little, Inc.,* **137,** 1–2 (June, 1938).—A few years ago heads were shaking over the fate of the hardwood distillation industry due to the inroads of synthetic production of methanol and acetic acid. How the expected demise of the industry was averted is an interesting story. Synthesis did not deprive it of a market. The problem was one of competitive prices and was solved by scientific methods and improved technic. Improvement in wood procurement, modern plant practice, and enlarged outlets for its products now assure the industry a long and useful life. Systematic development of the forests and increasing use of logging and sawmill wastes fully justify the industry's existence. The major improvement of the past fifteen years is in the stillhouse where direct recovery methods have displaced the wasteful lime method of fixing acetic acid. The modern plant extracts acetic acid with a solvent, from the vapor phase (Suida process), the liquid phase (Badger, Melle, and Brewster), or from a constant-boiling mixture (Othmer, Clamency, and Badger), or from the combined liquid and mixture (Badger), and the solvents are recovered. The charcoal end of the business presents a problem due to improved housing standards and reduced demands for charcoal as a fuel. Activated charcoal for sweetening chlorinated water and for deodorizing sewage offers a big field. Our present back-to-nature impulse is prompting people to cook out in the open, and charcoal serves this need in special packages for out-door fireplaces and special grills. G. O.

HISTORICAL AND BIOGRAPHICAL

Duddell Medal Award to Professor Hans Geiger. ANON. *Nature,* **141,** 929 (May 21, 1938).—The 1938 recipient of the Duddell Medal of the Physical Society, which is awarded to "persons who have contributed to the advancement of knowledge by the invention or design of scientific instruments, or by the discovery of materials used in their construction" is Professor Hans Geiger of the University of Tübingen. Early in this century he studied radioactivity under the late Lord Rutherford and demonstrated the possibility of detecting a single alpha particle by its electrical effect. The Geiger counter made possible the counting of both alpha and beta particles "and, in its more recent form, introduced by Geiger himself, even the differentiation of the effects produced by alpha and beta particles." Geiger and Nuttall determined the ranges of the alpha particles from various radioactive products and formulated the well-known rule connecting velocity and range, "which gives a means of calculating velocities from known ranges with remarkable accuracy." Geiger and Marsden observed "that some of the alpha particles in a beam directed on to a sheet of matter are deflected through very large angles and may even emerge on the side of incidence of the beam of alpha-rays. To explain the effect, Rutherford postulated the existence of large-angle scattering as the result of occasional single encounters with atoms. This led to the formulation of Rutherford's nuclear theory of atomic structure, with all its subsequent remarkable developments and far-reaching reactions on atomic theory." M. E. W.

James Ernest Marsh. F. SODDY. *Nature,* **141,** 903–4 (May 21, 1938).—Professor J. E. Marsh, University demonstrator in chemistry at Oxford since 1886, died on April 13, 1938, at the age of seventy-seven years. Between 1889 and 1910 he and his students published about twenty papers on the constitution and synthesis of camphor, a subject in which Professor W. H. Perkin was also actively engaged. "Marsh himself was the first to obtain, for the case of camphoric acid, *optically active* stereo-isomers of the *cis* and *trans* variety associated with the ring structure." He was an acknowledged authority and inspiring lecturer on stereochemistry. In later years he studied the "complexes formed by certain compounds of mercury with organic solvents and radicals, now ascribed, in the modern theory of valency, to the unique character of mercury among the metals and its power of forming covalent linkages of unusual type." M. E. W.

The Benjamin Franklin Memorial, Philadelphia. ANON. *Nature,* **142,** 9–10 (July 2, 1938).—On May 19 to 21 the Benjamin Franklin Memorial was dedicated at the Franklin Institute, Philadelphia. Among those who paid homage to the former printers' apprentice were scientists, statesmen, diplomats, philatelists, printers, and thousands of school children. Former Senator George Wharton Pepper said in his address: "From this time forward the Benjamin Franklin Memorial will be his [Benjamin Franklin's] permanent home, and I extend a hearty invitation to all people everywhere to visit him and make him their friend."

James Earle Fraser's heroic statue of Franklin in white Seravezza marble, more than twice life size, stands on a pedestal of rose aurora marble from Portugal. The sculptor, to use his own words, conceived of Franklin as "a massive figure, tranquil in body, with latent power in his hands, but with an inquisitive expression in the movement of his head and the alertness of his eyes, ready to turn the full force of his keen mind on any problem that concerned life."

"In a manner that would have aroused the keen interest of her famous ancestor," ten-year-old Louisa Johnston Castle of Wilmington unveiled the statue by turning a searchlight upon a photo-electric cell.

Special exhibits in the Wonderland of Science Museum depicted the progress in electricity, printing, paper-making, and heating since the time of Franklin. Lectures on pure and applied science were given by Sir James C. Irvine, C. E. K. Mees, G. N. Lewis, G. D. Birkoff, F. R. Moulton, A. L. Day, Louis Martin, T. H. Morgan, M. L. Fernald, W. R. Whitney, Abel Wolman, and H. N. Davis. M. E. W.

Centenary of the death of F. C. Accum. ANON. *Nature*, **141,** 1153 (June 25, 1938).—Friedrich Christian Accum was born at Buckeburg, Westphalia, on March 29, 1769, and died in Berlin on June 28, 1838. For nearly thirty years he lived at 11 Compton Street, Soho, London. He published a "Theoretical and Practical Chemistry" (1803), a manual on the analysis of minerals, a "Practical Treatise on Gas-Light" (1815), a "Description of the Process of Manufacturing Coal-Gas" (1819), a "Treatise on the Adulterations of Food, and Culinary Poisons" (1820–21), a "Treatise on the Art of Making Good Wholesome Bread," a "Treatise on the Art of Brewing," and "Culinary Chemistry" (1821). His "Crystallography," published in 1823, was the first work in English based on Haüy's system. In 1812 he became a director of the newly founded Gas Light and Coke Company. He supplied plans and estimates for gasworks and installed the gas lights at the Royal Mint. In 1822 he was given a post at the Technical Institute in Berlin. M. E. W.

Prof. Georges Urbain. ANON. *Nature*, **141,** 1130 (June 25, 1938).—On June 10 the fortieth anniversary of the first scientific paper of Professor Georges Urbain was observed in Paris. He received greetings at the Maison de la Chimie from his colleagues, students, and friends. Professor Lebeau, a former schoolmate, reviewed Urbain's contributions to the chemistry of the rare earths, phosphorescence, spectrochemistry, and the theory of valency. Professor Urbain studied chemistry first under his father and later under Pierre Curie. He is remarkably versatile and is well known for his work in sculpture and for his musical compositions for piano and organ and for piano and string quartet, several of which were played at the meeting. M. E. W.

Centenary of the death of P. L. Dulong. ANON. *Nature*, **142,** 127 (July 16, 1938).—Pierre Louis Dulong, professor of chemistry at the École Polytechnique, was born at Rouen on February 12, 1785, and died in Paris on July 19, 1838. At the age of twenty-six years he lost an eye in an accident with nitrogen chloride. With Alexis-Thérèse Petit (1791–1820) he made elaborate experiments on mercury and air-thermometers, published a notable memoir on the rate of cooling of bodies (1817), and in 1819 enunciated the Dulong-Petit law connecting the atomic weight and the specific heat of a solid. Some of Dulong's later researches were on the elasticity of high-pressure steam, a subject later studied by Regnault. M. E. W.

Science in the seventeenth century. E. N. DA C. ANDRADE. *Nature*, **142,** 19–30 (July 2, 1938).—In a Friday evening discourse at the Royal Institution on February 18th Professor Andrade discussed the authority of Aristotle, the mechanics of Galileo, the philosophy of Bacon and Descartes, the experiments of Robert Hooke, and the founding of the Royal Society. M. E. W.

TEACHING OBJECTIVES, METHODS, AND SUGGESTIONS

Problems in preparing pictorial material for classroom use. J. E. MENDENHALL. *Educ. Screen*, **17,** 119–20 (Apr., 1938). —Using the study units of *The Building America* series the author shows how the units were chosen, criticized by the teachers who were to use them, how the content of the units was assembled after many generalizations which are important in choosing and interrelating the facts to be used. Eight typical generalizations are stated. A most helpful feature of the paper is the characterization of a "best" photograph as one showing people in action, important facts, an artistic sense, a clear easily analyzed picture. A list of sources of good pictures is given. B. C. H.

GENERAL

Microphotography. H. O. BURDICK AND D. W. WEAVER. *Educ. Screen*, **17,** 185–6 (June, 1938).—By a combination of a Eastman Recomar 33 and an Argus 35-mm. camera the authors provide an apparatus that successfully prepared 35-mm. film strips and slides for their use in biology and chemistry. Working drawings showing the combination of the parts and a detailed description of the "photographic hybrid" produced make it possible for the reader to reproduce and use the apparatus. The combination resulting from these two instruments is characterized as having low cost, flexibility of use, and accuracy in focusing. B. C. H.

Esperanto for scientific papers and abstracts. ANON. *Nature*, **141,** 1007 (June 4, 1938).—The "Universala Esperanto-Kongreso" is to be held at University College, London, from July 30 to August 6. Dr. D. R. Duncan has pointed out in the *Scientific Worker* that this language is "intelligible to any educated European" without previous study and that it is therefore well suited for the scientific abstract of a paper which was originally published in a language little known outside its own country. He suggests that reports consisting largely of tables, such as the "International Critical Tables" might well be printed in Esperanto instead of in parallel columns in different languages. Esperanto is much used for scientific papers in Japan, and the *Bull. Soc. française des Electriciens*, the *Phare Médicale*, and the *Revista da Sociedade de Geografia do Rio de Janeiro* publish summaries in Esperanto. M. E. W.

"Frustration of Science" exhibition. ANON. *Nature*, **141,** 966 (May 28, 1938).—"The Scientists' Section of the Left Book Club held an exhibition on May 17–22 at the Unity Theatre, Goldington Street, N. W. 1, illustrating 'The Frustration of Science'." Charts, pictures, and select quotations illustrated the contrast between science as a constructive force in society and science as a weapon of destruction, science as a means toward arousing and satisfying communal needs and science merely as an instrument for profit...The meager sum spent on health research was contrasted with that devoted to investigations in chemical warfare...In the advertising of fictitious remedies for all kinds of diseases, approximately £3,000,000 per annum is spent, as compared with £139,000 per annum expended from Government sources on medical research in Great Britain..." M. E. W.

Science (K'o Hsüeh). G. D. LU. *Nature*, **141,** 954 (May 28, 1938).—In spite of the war, scientific work is still going on in China. The monthly journal *K'o Hsüeh* (*Science*) is similar in aims and format to *Nature*. The issue for January-February, 1938, contains articles on mathematics, chemistry, pharmacy, botany, and anthropology. "It should be realized that scarcely twenty years have passed since Western science began to be studied seriously in China. The application of Western science to Chinese conditions is by no means easy, since a large body of men educated in this tradition has not yet grown up. Moreover, the glaring necessities of the social situation require an emphasis on studies of immediate practical importance." M. E. W.

Rubber compounding. W. C. GEER. *Chem. Industries*, **42,** 640–8 (June, 1938).—Dr. Wm. C. Geer has devoted himself to the technical problems of rubber compounding since 1907. In this article he writes of developments in rubber compounding since 1914. Before that date it was a matter of guess—trial and error. A. T. B.

RECENT BOOKS

VITAMIN B_1 (THIAMIN) AND ITS USE IN MEDICINE. *Robert R. Williams*, Sc.D., and *Tom Douglas Spies*, M.D. The Macmillan Co., New York City, 1938. xvi + 411 pp. $5.00.

This is a book to be welcomed most cordially. It is timely; its subject matter is of large importance; its authors are outstandingly qualified; and they have written carefully and well. Published as one of the Macmillan Medical Monographs, it is naturally presented primarily from a medical point of view, and the sequence is therefore different from that which a teacher would probably adopt for a class in chemistry. In general arrangement, most of the medical part comes first, then the historical and experimental which includes the accounts of the differentiation, isolation, structure, and synthesis of the substance. Chapters VII, VIII, XVII, XVIII, and XX–XXIV deal largely with the quantitative problems of determination, distribution in foods, requirements in nutrition, and adequacy of dietaries or food supplies.

In a foreword Dr. McLester writes that in no other area of medical knowledge has there been recorded such a far-reaching advance as has been made during the past two decades in the field of nutrition; and he adds, "Pointing the way to the development of a healthier, more vigorous race, this advance marks an epoch in man's progress."

The first six chapters are addressed directly to the physicians, who, it is stated, are beginning to realize that subclinical forms of vitamin B_1 deficiency occur frequently, though "the effects of a persistent, slightly faulty diet may not be detectable for years." Beside faults in the food, there may be disturbances of absorption of the vitamin, or increased need for it in the body. The authors emphasize the view that prolonged inadequacy, either from dietary lack, failure of utilization, or increased demand, produces a variety of borderline states of ill health, which are rarely well defined and rarely the uncomplicated result of shortage of one nutritional factor alone. Hence even though frank cases of beriberi are not common in this country, they hold that cases of suboptimal vitamin B_1 nutrition are probably more common than has hitherto been supposed. This point of view leads to very careful considerations of the quantitative questions of adequacy, in both the clinical and the experimental parts of the book.

With Chapter IX begins the more chemical phase of the story. The review of pioneer observations gives prominence to Takaki, to Eijkmann, and to Fraser and Stanton (a judicious international distribution of honors!).

The differentiation of vitamin B_1 is reviewed from the standpoint of present-day knowledge and thus throws much light upon other essential substances as well. The discussions of isolation, structure, synthesis, chemical reactions, and the origin of the modern name *thiamin* all carry a very special interest and authority because of the senior author's long, active, and outstandingly successful identification with this important line of chemical research. Convenience is also enhanced by the inclusion in these chapters of concise summaries of the chemistry of closely related substances.

The discussions of the stability of the vitamin under different conditions illustrate anew how a given experiment, if carefully planned, may serve an immediate practical purpose and also have a permanent theoretical value which the "pure" chemist may fail to appreciate because it appeared in a "utilitarian" setting.

Chapters XIV, XX–XXII, and XXV–XXIX contain effective presentations of the authors' views as to how the vitamin acts in the living cells and tissues. The reviewer is not enough of a physiologist to attempt such condensation as would be necessary to summarize these views here, and is further deterred by the fact that the corresponding theories of action of vitamin C and riboflavin are not yet sufficiently developed to be given that place in the picture, and weight in the argument, which they may soon command.

Having offered the reader a thorough acquaintance with thiamin (vitamin B_1) as a chemical individual which has been isolated, synthesized, extensively and intensively studied, and made as available as other pure substances, the authors recommend (pp. 169, 216, and elsewhere) that hereafter all vitamin B_1 values be expressed in terms of actual weight of thiamin (or crystalline thiamin chloride) rather than in terms of *any* arbitrary "unit," however authoritatively agreed upon. Micrograms (gamma) of thiamin (vitamin B_1) per gram of sample—which, of course, can also be conveniently called parts per million—fortunately make easily manageable numbers in expressing food values. Thus the authors estimate representative vitamin B_1 values (among others) as follows: rice unmilled 2.0 to 3.0, half-milled 1.2, well-milled 0.5 to 0.6, polished and washed 0.02 gamma per gram (p. 230); beef muscle 0.4 to 0.5, lamb and mutton 0.5, pork muscle 3.0, egg 1.0, dry beans and peas 2.5 to 4.0, string beans 0.5, green peas 1.5, peanuts 8.0, whole wheat 5.0, white bread (and patent flour) 0.5, potato and sweet potato 0.7, watercress 0.5 gamma of thiamin per gram, or parts per million (pp. 236–9).

Even with the rapid recent accumulation of data on food values and advance in our knowledge of nutritional functions, it is still too early for generalizations as to the margins of safety in their vitamin B_1 content that American dietaries commonly now *do*, and in future *should*, carry; but anyone who would (or in near future may) study this complex question will find Williams and Spies' full, critical, and objective analysis of the evidence up to 1938 a most valuable fundamental "bench mark" and point of departure.

Expression of appreciation of the many excellencies of the book must here be curtailed by the necessity of brevity in this review.

Every chapter gives evidence of having been thoroughly thought through and is written with the cogency of authoritative first-hand knowledge at the same time that it is abundantly documented. Chemists, physiologists, and physicians alike are most fortunate in having available in such admirable form the joint findings of an outstandingly able chemist and nutritional experimenter who has devoted a quarter-century to the subject and of an exceptionally active, alert, open-minded, and scientific representative of modern medicine.

The book as a whole is a fine example of chemistry in the service of medicine and health, and of the development of modern medicine as a quantitatively exact science.

HENRY C. SHERMAN

COLUMBIA UNIVERSITY
NEW YORK CITY

ASPECTS OF SCIENCE. *Tobias Dantzig*, Professor of Mathematics, University of Maryland. The Macmillan Company, New York City, 1937. xi + 285 pp. 7 figs. 14 × 21 cm. $3.00.

"This book," according to the author, "is an essay on faith. . . . Faith that the world revealed to man by his senses was not a sheer chaos, but a universe; that this universe was accessible to his reason." The classical foundations of physical science have been destroyed by Einstein's theory of relativity and Heisenberg's principle of indeterminacy. What, then, is the philosophical significance of these new concepts for the future of science?

The answer to this problem is given in twelve chapters which contain a most stimulating discussion, written in an extremely interesting manner. Because he is a mathematician, the author naturally stresses the mathematical aspects of the scientific developments from the time of Galileo to the present. However, there is an avoidance of any highly technical remarks, no "higher

mathematics" is brought in, and, on the other hand, there is very little of that metaphysical discussion which is found in the works of other recent writers on the same topics.

It is difficult to give, in such a brief review, any even moderately satisfactory summary of the contents. The work of Galileo and his experiences with the Church are described in one of the most interesting chapters (the third), "The Dawn of an Era." Chapter XI, entitled "Models," should be read by all those who still fondly believe that the mathematics of Schroedinger and Dirac is only a passing vogue which will be followed by a really "understandable" interpretation of nature in "simple language."

Chapter XII, the last one, entitled "Universe of Discourse," contains a summary of what the author regards as the present philosophy of science. The titles of the other chapters are as follows: I. The Causal Chain; II. The Appeal to Reason; IV. Number; V. The Infinite; VI. The Crisis; VII. In Quest of the Absolute; VIII. The Straight and the Flat; IX. On Rigid Standards and X. Signals.

The reviewer has no hesitation in recommending the work as containing a well-balanced and illuminating discussion of the interpretation and philosophical implications both of the physics which preceded "the Crisis" and of those developments which have occurred during the past quarter century.

SAUL DUSHMAN

RESEARCH LABORATORY
GENERAL ELECTRIC COMPANY
SCHENECTADY, NEW YORK

PROBLEMS IN ORGANIC CHEMISTRY. *Ernest Hamlin Huntress*, Associate Professor of Organic Chemistry, Massachusetts Institute of Technology. McGraw-Hill Book Company, Inc., New York City, 1938. xi + 270 pp. 14 × 20.5 cm. $2.25.

As a basis for the production of the book, the author cites "fifteen years' experience in teaching the introductory course in organic chemistry at the Massachusetts Institute of Technology. It has sprung from the growing conviction that the efforts of the student can be greatly facilitated and his ultimate mastery of the subject markedly improved when his individual study of the material amply supplied by textbooks and lectures is guided by much further suggestion of what he needs to know than can possibly be given during class time."

This problem book consists of four divisions: "the first devoted to the monofunctional compounds of the aliphatic series, the second to corresponding compounds of the aromatic series, and the third to polyfunctional compounds (or compounds with more than one single type of function) drawn from either or both series." These four divisions are subdivided into chapters "each of which deals mainly with some definite class of compounds. Certain parts are still further subdivided into sections with closely similar classes. Each part is so constructed that, after suitable drill in the simpler aspects of the behavior of its particular class of compounds, attention is drawn to the coordination and cumulation of the class with the classes which have preceded it. Throughout the book this principle of 'coordinative cumulation' has been emphasized as a means of development of power in the subject." A fourth division contains a miscellaneous review and advanced problems.

Eighty-seven pages are given to problems on the acyclic compounds under the chapter headings: hydrocarbons, monohydric alcohols, alcohol derivatives, monobasic acids, acid derivatives, amides and amines, carbonyl compounds, and a review of monofunctional classes. The aromatic series is covered in eighty-one pages under the headings: isocyclic hydrocarbons, aromatic halogen compounds, aromatic carbonyl compounds, aromatic carboxylic acids and their derivatives, sulfonic acids, nitro compounds, phenols and aromatic alcohols and aromatic ethers, amines, diazonium compounds, and a general review for the aromatic series. In the third division of thirty-five pages, polyfunction compounds and other topics are considered: polyhydric alcohols and related substances, oils, fats, and waxes, polybasic acids, substituted acids and derivatives, carbohydrates, and special topics, whereas the fourth division contains sixty-seven pages dealing with general information, definitions, industrial type, review equations, isomerism, synthesis, distinctions and separations, true and false types, essay type, structural proofs, comprehensive and correlative types, and Beilstein problems.

A total of eight hundred thirty-five type problems, subdivided into about five thousand specific exercises, are included. Graphic formulas are included where a clear concept of the arrangement of the atoms in the molecule seems essential to the understanding of the problem.

This book offers an excellent additional teaching tool to those who are interested in supplementing their teaching by exercises and problems other than those supplied in the usual textbooks.

ED. F. DEGERING

PURDUE UNIVERSITY
WEST LAFAYETTE, INDIANA

OBJECTIVE QUESTIONS IN COLLEGE CHEMISTRY. *Alexander Calandra*. Edwards Brothers, Ann Arbor, Michigan, 1938. iv + 151 pp. 21 × 27 cm. $2.50.

This book represents an effort to supply a source of "objective" or "new type" questions to replace tests of the essay type. These questions are so phrased that they will fit any of the customary answer forms and thus may be rapidly or machine graded.

In order that the questions may have some continuity, the author has followed the scheme of presentation used in Briscoe's GENERAL CHEMISTRY FOR COLLEGES which differs but slightly from the traditional order, hence they may be used with any textbook. They are arranged in thirty-nine groups corresponding to the chapter headings of Briscoe's book. The questions are clearly planographed on both sides of the pages and extend its full width. Unfortunately, there is no arrangement of spaces for answers, thus restricting the use of the book in regular class work.

Four types of questions are used in this book:

1. *The multiple response type*
   Four possible responses are suggested to a given question. Any number of responses may be correct.
2. *The multiple choice type*
   Four possible choices are suggested. Only one is correct. This type of question is useful in avoiding ambiguities which would arise were the question stated as a multiple response question.
3. *The arrangement type*
4. *The matching type*

Each question calls for four responses or multiples thereof up to twenty-four in number. The inquiry, statement, or situation that constitutes the question is followed by or includes four statements, one or all of which may constitute the right answer or statement. Thus the student is not aided by being advised of the number of correct responses. There are over 8100 questions, each consisting of four or more parts.

The statements are clear, simple, and direct and their meaning should be clearly and readily understood. There are few duplications or like questions differently worded. Such leading words as "all," "almost," "every," and guiding statements and clues are rarely found as well as the familiar stereotype forms so commonly used. There are many ingenious situations that require the student to balance the merits of one answer against another—the "thought type" of question.

No claim whatever is made for the reliability or validity of these questions. They should be carefully analyzed, therefore, before being used for examinations. An analysis of a sampling of these questions showed biserial correlations of total scores with individual items, ranging from −0.1 to 0.9.

A large number of the questions have been used in the classes in chemistry at Brooklyn College.

An ingenious scheme is given whereby any question with its one to twenty-four answers may be represented by only one letter. A tabulation of the correct answers to all the questions can be obtained from the author at Brooklyn College, New York City.

The excellent compendium of questions can be used economically by all teachers of general chemistry, and no department can well afford to be without it. It is also a valuable study help and guide for poor students as well as exceptional ones.

O. M. SMITH

OKLAHOMA A. AND M. COLLEGE
STILLWATER, OKLAHOMA

GERMAN FOR CHEMISTS. *John H. Yoe*, Ph.D., Professor of Chemistry, University of Virginia, and *Alfred Burger*, Dr.Phil. (Vienna), Research Associate in Chemistry, University of Virginia. Prentice-Hall, Inc., New York City, 1938. xiv + 537 pp. 15 × 23 cm. $4.50.

Under whose tutelage should science students be trained to read professional literature in foreign languages? The modern language departments in our colleges, *sua cuique voluptas*, are primarily interested in grammar, linguistics, and belles lettres, their courses are mainly designed to train teachers of languages. This is hardly the atmosphere in which to acquire the ability to read scientific literature rapidly, whose factual matter is usually beyond the scientific attainments of the instructor. The reviewer, like many other science teachers, prefers that Caesar's things be rendered unto Caesar, and that German for chemists be taught by a member of the chemistry staff. What may be lost in neglecting fine grammatical points and so forth, will be more than compensated for by expert understanding of the subject matter. Good students, after a little practice and guidance, soon acquire sufficient *Sprachgefühl* to carry them over many difficulties.

The text under consideration will serve under either of these auspices, but only rarely will a member of the German department have sufficient chemical knowledge to cope with some parts of the text. This rather advanced material, however, greatly increases the value of the book to the chemist.

In their preface the authors write, "The student who wishes to read articles in German chemical books or periodicals should have a background of at least one year and preferably two years of German, that is, a comparatively wide vocabulary of common words, a thorough knowledge of English and German grammar, and some experience in reading general German texts.....The present volume has been designed to introduce the students in chemistry to German chemical literature. The main emphasis has been laid on covering practically every branch of chemistry and in bringing the facts up-to-date.....The student will find this reading also useful as a short treatise on chemistry, helping him to review and even extend his knowledge of the subject.....Any descriptive chapter will necessarily be easier reading than a speculative or theoretical treatise.....Synonyms have been used extensively to familiarize the student with different terms of the same meaning. Likewise, whenever several modes of spelling are in use for one word, the various ways of spelling it have been used in different places. Words recently Germanized and originating from Latin or French influences on the German language are represented both in their new form and in their former usage."

The book is composed of nine chapters. Part I (pages 2–77) consists of a series of graded "sentence exercises in both languages, and it is hoped that the student will acquire a working vocabulary from these simple exercises. The arrangement of frequently used words and expressions in sentences which may be found again in the respective chapters will make it easier to remember fundamental terms than it would be if they were acquired from a rigid word list." The German text of these sentences on the left page is faced by the corresponding English text on the right page. The reviewer has noted this device in other chemical readers and has wondered whether the student may not delude himself with his facility in reading the foreign text when in fact he is unconsciously doing little beyond reading the English translation that stares up at him from the other page.

Parts II, Inorganic (pages 81–157), III, Organic (pages 161–242), IV, Analytical (pages 245–306), V, Physical (pages 309–71), VI, Colloid (pages 375–406), VII, Chemical Technology (pages 409–73), VIII, Physiological (pages 477–99), are divided into numerous sub-topics. This constant shift within the main sections ought to keep up the student interest, which is likely to be severely taxed by long, detailed discussions of a single topic. This variety affords not only material for different interests and capabilities, but it has the great practical advantage of necessitating the constant introduction of new words. Part IX (pages 503–37) is composed of excerpts from German chemical books and periodicals, and is "recommended to the advanced student, since a few of the difficulties encountered here are greater than in the preceding parts."

The text is mostly original, with occasional quoted passages. It makes interesting reading and is full of sound chemical facts and theory. Free use is made of equations, structural formulas, mathematical expressions, and so forth. No hints for the translation of idioms or tricky passages are given; in fact the volume contains no English beyond the Preface, Table of Contents, and the sentences in Part I. There is no vocabulary, which the authors state would have doubled the size of the volume. The reviewer applauds this omission because facility in using a dictionary cannot be acquired too early.

Any student who finds himself at home in this reader can approach the original literature without fear. The authors, including Dr. Mayer Bodansky, who wrote Part VIII, have done a good piece of work. The publisher has done his part well, except in the matter of the price, which seems unduly high.

RALPH E. OESPER

UNIVERSITY OF CINCINNATI
CINCINNATI, OHIO

BREATHE FREELY! THE TRUTH ABOUT POISON GAS. *James Kendall*, M.A., D.Sc., F.R.S., Professor of Chemistry, University of Edinburgh; formerly Lieutenant-Commander in the United States Naval Reserve, acting as Liaison Officer with Allied Services on Chemical Warfare. D. Appleton-Century Co., New York City, 1938. xi + 179 pp. 12 × 18.5 cm. $1.50.

This is a book with a purpose. The author qualifies as an expert on chemical warfare so that he can testify to the British public. In fact he is an expert, having been on the inside of things during the World War, and having kept up with developments ever since. He marshals facts and figures as to the amounts of gas used and what was accomplished thereby during the war. He makes it plain to the man on the street just what gas can do and what it cannot do. His chief aim is to dissipate the terror that has been inspired in the minds of the public by sensational articles depicting the destruction of a whole cityfull of people by a few pounds of a super-super-poison gas dropped from a plane. A hundred may be killed by the panic which results from the cry of fire in a crowded theater when the fire itself may have done no harm. If a gas attack comes panic is the only thing to fear; people who remain indoors in properly closed rooms will not get enough gas to hurt them and the streets will soon be cleaned up.

The style is direct and frequently colloquial. The book is written for Britishers, particularly for those who dwell in the large cities, but it contains a great deal of information that will interest people in this country where we do not fear such attacks. Even among well-informed chemists many wrong ideas are prevalent. Chemistry teachers and students will do well to read this little volume. While it was not written for chemists, it contains much that chemists should know and do not.

E. EMMET REID

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TRADE ANNOUNCEMENTS

Aluminum Company of America Prepares Display Chart

In order to assist chemistry and industrial arts teachers in high schools, vocational schools, and secondary schools in presenting the chemistry of aluminum to their students, *Aluminum Company of America* has prepared a display chart on aluminum.

On the front side of the chart, interesting scenes depicting the mining and manufacture of the raw materials used in the production of aluminum serve as a background for actual samples of the various raw materials. The electrolytic cell in which the metal is made is also graphically illustrated, while the history of aluminum and its chemistry are briefly described. On the reverse side of the chart, a diagram traces each step in the production of the metal from the mining of the ore, bauxite, through the fabrication of the primary aluminum products.

The chart is $17^7/_8$ by $27^1/_2$ inches in size and is designed to be hung on the class-room wall. It may be secured free of charge by teachers in accredited schools who will write to Aluminum Company of America, 2106 Gulf Building, Pittsburgh, Pa., on the letter heads of their schools.

New Cartridge Dehydrator

According to a recent announcement the new *Henry Cartridge Dehydrator*, originally designed for air conditioning and refrigeration, is finding increasing use where need exists for removal of moisture from chemicals in solution, and in air drying.

Major features of this Henry dryer are its patented dispersion tube and replaceable dehydrant cartridge. The perforated dispersion tube exposing the entire volume of dehydrant to penetration by the fluid or air extends along the center axis of the dehydrant column. This construction is claimed to reduce the pressure drop, prevent channeling and resultant loss of efficiency so often found in dryers of conventional design. A strong compression spring provides positive sealing of dispersion tube to inlet fitting, preventing by-passing between outside of dehydrant cartridge and inner surface of dehydrator shell.

Every trace of moisture is removed from these dryers and replaceable cartridges by the new exclusive Henry vacuum process. The dryers then are sealed with dehydrated air, insuring absolute dryness until moment seal cap is loosened for installation.

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A new catalog describing latest additions to the Henry line may be obtained by writing the *Henry Valve Company, 1001–19 North Spaulding Avenue, Chicago, Illinois.*

Photo-Electric Slit-Ocular

Pfaltz & Bauer, Inc., Empire State Bldg., New York, offer a pamphlet on their Photo-Electric Slit-Ocular. The Slit-Ocular with Ocular photo cell makes every microscope an objective photometer. This device is particularly valuable in spectrographic analyses as it permits measurements of the density of the spectral lines of spectrograms and so permits quantitative analyses of material.

The Slit-Ocular consists of the illuminating device which is attached beneath the stage of the microscope instead of the condenser. The light source is a 4 V 1-amp. bulb which illuminates the spectrogram. The Slit-Ocular is attached to the microscope instead of the eyepiece and the terminals are connected with a very sensitive galvanometer. The deflection of the galvanometer corresponds to the light absorption of the spectral line.

Full details and copy of leaflet will be sent by addressing the manufacturer.

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A new eight-page catalog describing the "Thermionic Amplifier for Voltage Measurements in High Resistance Circuits" has just been released. This instrument adapts any potentiometer of suitable range for glass electrode measurements and other measurements of potential in high-resistance circuits. It is useful in polarization studies, in measurements of corrosion and oxidation-reduction potentials and in the measurement of resistors of high values. Particularly advantageous is the fact that it draws a negligible current from the source being measured, less than 10^{-14} amperes at balance.

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The compound, which is a white, crystalline, and almost tasteless solid, soluble in water at room temperature to the extent of approximately 1 in 1000, has been supplied by *Merck & Company, Inc.*, for clinical investigation, and arrangements are being made to manufacture the new drug at the *Merck* plant in Rahway, New Jersey.

Fluorescent Chalk

A fluorescent chalk which glows with a strong green light and is visible at a distance has been developed recently by the *Westinghouse Electric & Manufacturing Company.*

This new material appears and marks like ordinary chalk under normal light. It glows in the dark when irradiated with ultraviolet rays such as from a sunlamp enclosed in a black globe.

Doctors find this chalk useful for jotting down memoranda on a blackboard during the course of a fluoroscopic examination. It also provides a new tool for the lecturer who, during the showing of stereopticon or moving pictures, wishes to put a visible written message on the blackboard for his audience. This novel medium is especially valuable for use during the showing of moving pictures with sound.

Moisture-Proof Paper Lacquer Produced

A new paper lacquer which is moisture-proof has been developed by *E. I. du Pont de Nemours & Company.*

Designed primarily for use on packages, the new lacquer affords a protective film which is impermeable to water vapor. Its purpose is to prevent moisture from entering into packaged goods which should be kept dry, and similarly to retain the desired quantity of moisture in those which should be moist.

Aside from its protective features, the lacquer adds brilliance to colors on labels. It prevents offsetting and smearing of inks on labels of products which must be packaged while hot. It is resistant to scuffing and scratching and can be made to resist alcohol, greases, and other reagents.